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"Intelligent and Integrated Chemical Engineering for Global Challenges"

ABSTRACT BOOKLET

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Sunway University, Malaysia

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PLENARY SPEAKERS

Sustainability Assessment: A Process Systems Engineering Perspective

Santanu Bandyopadhyay
Indian Institute of Technology Bombay
Corresponding Author: santanub@iitb.ac.in

ABSTRACT

Sustainability assessment is increasingly central to guiding technology choices in an era defined by net-zero ambitions, circularity goals, and growing ecological pressures. Yet relative sustainability assessments often yield conflicting outcomes due to methodological inconsistencies. This plenary introduces a generalised, mathematically rigorous framework that identifies normalisation and aggregation functions satisfying desired mathematical properties for robust multi-criteria evaluation, thereby providing a consistent and defensible basis for comparing alternatives across multiple indicators. The talk will illustrate why relative sustainability assessment is crucial for emerging energy and chemical engineering systems, particularly in renewable energy domains where technologies may involve hidden environmental or ecological trade-offs. It will further connect sustainability assessment to the core principles of process systems engineering—modelling, optimisation, multi-criteria decision analysis, and systems integration—highlighting PSE's role in enabling intelligent and integrated sustainability evaluation. The plenary will conclude by outlining promising directions for future research.

Keywords: Sustainability assessment; Process systems engineering; Multi-criteria evaluation

Beyond Intelligent Systems: The Mindset Driving Integrated Chemical Engineering for Global Challenges

Khalik Mohamad Sabil
PETRONAS Research Sdn Bhd
Corresponding Author: khalik.mohamadsabil@petronas.com

ABSTRACT

The unprecedented acceleration of artificial intelligence, digitalisation, advanced materials and disruptive technologies is redefining the frontiers of chemical engineering. Yet, technological sophistication alone will not solve the increasingly interconnected challenges confronting our world. The next frontier demands a fundamental shift—from intelligent systems to intelligent integration, where technology, human ingenuity and purposeful collaboration converge to catalyse transformative impact.

This presentation explores the mindset required to navigate this paradigm shift and reimagine the role of chemical engineers in an increasingly complex and uncertain world. Drawing on perspectives across academia and industrial R&D, it examines how engineers can transcend conventional disciplinary boundaries, orchestrate innovation ecosystems, and bridge the critical divide between scientific discovery and value realisation. It challenges the traditional notion of technological success, advocating a transition from simply achieving technology readiness towards creating solutions that are deployable, scalable, sustainable and ultimately valuable.

As global challenges become increasingly multidimensional, the future belongs not merely to those who develop the most intelligent technologies, but to those who can connect, integrate and translate them into meaningful impact.

Keywords: Intelligent integration; Digital transformation; Innovation ecosystems; Sustainable engineering

Redefining Chemical Engineering Education in the Era of Global Challenge: A paradigm shift

Suzana Yusup
Sunway University Malaysia
Corresponding Author: suzanay@sunway.edu.my

ABSTRACT

In this 21st century, the information and digital age play significant role in most aspects of our life including education. Humanity faces deeply interconnected and borderless. Further, human anthropogenic activities influenced the climate and the ecosystem. Undeniably, the global chemical engineering sector seeks for a profound structural shift driven by these global challenges where decarbonisation, bioprocess acceleration, uprise of semiconductor sector, demand of clean energy and nanoscale manufacturing that is more sustainable. The traditional academic Chemical Engineering curricula remain optimized and relevant to support the oleochemical, oil and gas, petrochemical refining but the divergence of current needs created a critical competency gap, specifically in data analytics, dynamic process control, and multi-scale systems engineering. The talk highlights the history of chemical engineering education to meet industrial revolution progressing towards knowledge economy, comparative of traditional core competencies against that of emerging Chemical engineering education, significant of chemical engineering education to address the global challenges and paradigm shift of Chemical Engineering Education.

Keywords: Chemical engineering education; Digital transformation; Sustainable engineering; Global challenges

KEYNOTE SPEAKERS

Computer Aided Molecular Design of Deep Eutectic Solvents: Challenges and Opportunities

Jecksin Ooi

School of Engineering and Physical Sciences, Heriot-Watt University Malaysia, Jalan Venna P5/2, Precinct 5, 62200 Wilayah Persekutuan Putrajaya, Malaysia

Corresponding Author: j.ooi@hw.ac.uk

ABSTRACT

With the growing emphasis on eco-friendly and sustainable processing, deep eutectic solvents (DESs) have emerged as potential 'green' solvents for a wide range of applications. DESs are defined as solvents that are formed at a correct molar ratio of both hydrogen bond acceptor (HBA) and hydrogen bond donor (HBD), where they have a eutectic point far below the melting temperatures of the individual components. Owing to the tunability of their physicochemical properties through the selection of HBA, HBD and the molar ratio, DESs are often known as 'designer solvents'. Nonetheless, several challenges remain in the application of DESs across different processes. It is difficult to select DESs with targeted properties from a huge search space since there are numerous possible combinations of HBA and HBD in forming DESs. Most existing studies performed selection of DESs based on bottom-up approach, which relies heavily on trial-and-error experimental studies, design heuristics and expert judgement. As a result, the systematic identification and selection of DESs for specific applications remains a non-trivial task.

Computer aided molecular design (CAMD) is proposed to guide the design and selection of DESs for targeted application. It has been a powerful technique used in the field of chemical product design to design molecules/ solvents that satisfy a specified set of targeted performance from a pool of molecular building block. However, the application of CAMD depends strongly on the availability of the property prediction models. For DESs, the availability of property prediction models for some properties remains limited. This limitation creates the opportunities to integrate machine learning approach to develop predictive models for attributes where no prediction models are available. Once prediction model is available, CAMD tools can be developed to inverse property prediction models to predict DESs for various applications.

Keywords: Computer aided molecular design; Deep eutectic solvents; Machine learning; Property prediction

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Parametric and Kinetic Analysis of Tin Oxide Catalysed Polycondensation of Glycerol with Sebacic Acid

Pauline Shi Peng Tan[1], Sara Shahruddin[2], Siti Kholijah Abdul Mudalip[1], Nur Amalina Samsudin[2], Zulkifly Jemaat[1], Siti Fatihah Salleh[2], Ashwin Charles Benedict[1], Sim Yee Chin[1]

[1] Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, 26300 Kuantan, Pahang Darul Makmur, Malaysia
[2] PETRONAS Research Sdn. Bhd., Lot 3288 and 3289, Off Jalan Ayer Itam, Kawasan Institusi Bangi, 43000 Kajang, Selangor Darul Ehsan, Malaysia

Corresponding Author: chin@umpsa.edu.my; sarashahruddin@petronas.com

ABSTRACT

Polyglycerol sebacate (PGS) is a highly versatile elastomer for various biomedical and engineering applications. Its properties can be tailored by manipulating synthesis conditions and catalysts. The present work employed heterogenous catalyst, Tin (II) Oxide, for the synthesis of PGS by the polycondensation of glycerol with sebacic acid in a solvent-free system with nitrogen gas blanket. The effect of stirring speed, reactant molar ratio, catalyst loading and temperature was investigated. The products were analysed for their physical properties, functional group, chemical structure, molecular weight distribution and conversion efficiency. The best operating conditions driven by the reaction progress were determined as stirring speed 400 rpm, molar ratio of glycerol to sebacic acid 2.5:1 and catalyst loading 0.03 wt% and reaction temperature 210 °C. A kinetic model constituted of elementary reactions was fitted to the experimental acid value data obtained during the reaction carried out at various temperatures (180-220 °C). The kinetic constant and activation energy of the respective elementary reactions were determined. A well agreement between simulation results and experimental data has verified that the developed kinetic model could predict accurately the course of reaction at different temperatures and hence the product parameters, such as the average molecular weight and polydispersity.

Keywords: Parametric; Kinetic; Polyglycerol sebacate; Polycondensation; Tin Oxide

Materials that Heal: Engineering Bio-Inspired Nanocomposites for Medical Applications

Siew Shee Lim

Faculty of Science and Engineering, Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia.

Corresponding Author: SiewShee.Lim@nottingham.edu.my

ABSTRACT

The development of bioactive medical materials is essential for overcoming the limitations of conventional biomaterials, including poor bioactivity, mechanical performance, and tissue integration. This paper presents an engineering approach to developing bio-inspired nanocomposites that mimic structural and biological features of the extracellular matrix to promote tissue regeneration. Chitosan was employed as a biocompatible and biodegradable based biomaterial, while nanomaterials were incorporated to enhance mechanical properties, cell–material interactions, osteoconductivity, and biological functionality. Porous chitosan-based nanocomposite scaffolds were fabricated through direct blending, freezing, and freeze-drying, followed by biofunctionalization with calcium, magnesium ions, and fibronectin. These modifications enhanced bone-cell growth and early differentiation. The approach was extended to 3D-printed PEGDA–chitosan–nanohydroxyapatite scaffolds, providing improved structural precision and potential for patient-specific applications. Beyond bone regeneration, fish-scale gelatine was developed into electrospun nanofibres and gelatine-coated bioglass for wound healing. Microwave-assisted synthesis of chitosan–silver nanoparticle membranes significantly reduced processing time, thereby lowering energy consumption, while demonstrating reproducible antimicrobial activity against *E. coli* and *S. aureus*. Overall, controlled synthesis, nanostructure integration, biofunctionalization, and advanced fabrication can transform biomaterials into multifunctional healing platforms. Future work will focus on *in vivo* evaluation and translation towards regenerative medical applications, particularly in bone tissue engineering and wound healing.

Keywords: Nanostructured scaffolds; Chitosan-based nanocomposites; Tissue engineering; Wound healing

Engineering Ecosystem: Matching Chemical & Bioreactor Solutions to Your Process Needs

Johnny Lau
IKA Works (Asia) Sdn Bhd
Corresponding Author: johnny.lau@ika.my

ABSTRACT

Modern process development requires highly adaptable, scalable solutions that bridge the gap between chemical synthesis and advanced bioprocessing. This presentation, "Engineering Ecosystem: Matching Chemical & Bioreactor Solutions to Your Process Needs," explores how integrated reactor technologies streamline R&D workflows and accelerate scale-up. We will examine a comprehensive engineering ecosystem by highlighting three core IKA platforms. First, the EasySyn reactor system provides exceptional modularity and precision for organic synthesis, crystallization, and API development. Second, the highly versatile LR system delivers robust control for optimizing complex mixing, dispersing, and reaction processes, ensuring a seamless transition from the laboratory to pilot scale. Finally, we explore the HABITAT research bioreactor, an innovative, ergonomically designed platform built to automate and optimize bioprocessing and fermentation workflows. By understanding the distinct capabilities of the EasySyn, LR, and HABITAT systems, process engineers and researchers can tailor their infrastructure to exact project demands. Attendees at SOMChe 2026 will gain actionable insights into selecting the right technology to enhance reproducibility, reduce time-to-market, and drive innovation across both chemical and biological applications.

Keywords: IKA; Chemical synthesis; Formulation; Bioprocess

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Advancing Lubrication with Esters: Bridging Sustainability and Performance

Yen Yee Chong[1, *], Jenalis Muhammad Hafiz[1], Abdul Hasif Bin Abd Rahim[1]

[1] Oleon Port Klang Sdn Bhd, Selangor, Malaysia

Corresponding Author: chong.yenyee@oleon.com

ABSTRACT

As lubricant innovation moves toward safer chemistries, stronger environmental performance and more demanding application functionality, biobased esters offer a strategic platform for future formulations. Their advantage lies in molecular design flexibility, enabling formulators to tune ester structure and additive compatibility for targeted performance. Through selected technical case studies, this keynote showcases Oleon's expertise in three high-value application areas: fire-resistant hydraulic fluids, environmentally acceptable greases and conductive fluids for electrified mobility. The case studies demonstrate how ester structure and additive response can be translated into measurable performance using industry-relevant tests, including hydraulic and fire-resistance approvals, grease ageing and shear-stability assessments, four-ball wear testing and electrical resistivity measurements. The central message is that sustainability and technical performance should no longer be treated as competing priorities, but as integrated design objectives.

Keywords: Esters; EALs; Greases; Hydraulics; E-mobility

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Evaluation of total suspended solids removal in coal mine wastewater by chemical and electrochemical methods

Yap Yong Chun[1], Issabayeva Gulnaziya[1*], Chong Woon Chan[1], Wong Mee Chu[2]

[1]Univeristi Tunku Abdul Rahman, Department of Chemical Engineering, 43000 Kajang, Malaysia

[2]Univeristi Tunku Abdul Rahman, Department of Mechanical & Materials Engineering, 43000 Kajang, Malaysia

Corresponding Author: gulnaziya@utar.edu.my

ABSTRACT

This study presents results on the application of chemical and electro-coagulation (EC) treatments for Total Suspended Solids (TSS) removal in high level TSS coal mine wastewater. The objective was to select optimal coagulant type and dosage, electrodes material and current density for enhanced TSS removal. The optimal dosages of chemical coagulants were determined to be as follows: 0.12 g/L- aluminium sulphate (alum), 0.05 g/L - Polyaluminum Chloride (PACl) and 0.025 g/L for cationic Polyacrylamide (PAM) and Polydiallyldimethylammonium chloride (PDADMAC), at which TSS removal exceeded 99%. Whereas the optimal current densities in electrocoagulation were 10 mA/cm² and 15 mA/cm² for aluminium and iron electrodes, respectively. In terms of the coagulants cost and efficiency evaluation, PACl showed to be the optimal choice with excellent TSS removal efficiency of 99.7% at the total treatment cost of RM 0.08/m3. Overall, this study demonstrated that chemical coagulation remains preferable treatment for high TSS removal from actual coal mine wastewater in terms of efficiency and cost.

Keywords: Chemical coagulation; Electro-coagulation; Suspended solids; Coal-mine wastewater

TECHNICAL PRESENTATIONS

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Carbon-constrained multiple energy resources targeting with supply limits using the Pinch analysis approach

M. U. Ashna[1], Santanu Bandyopadhyay[1]

[1] Department of Energy Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

Corresponding Author: 19i170006@iitb.ac.in

ABSTRACT

Carbon-constrained energy sector planning is necessary to mitigate climate change, support the sustainable energy transition, reduce environmental impacts, ensure energy security, and support policy and regulatory development. Energy sector Planning includes existing energy sources, energy demand, and under-construction and pipeline projects (energy resources). This framework is similar to Resource Conservation Networks (RCNs) in Pinch analysis. In real-life problems, multiple energy resources can be present. RCNs problems in Pinch analysis target multiple resources within the carbon-constrained framework. In Pinch analysis, targeting multiple energy resources solely based on prioritized costs may not yield an optimal solution. Therefore, a replacement condition for resources is identified and mathematically formulated. Existing energy-sector planning often treats resources as having unlimited energy flows. In reality, resource flow can be restricted in the energy sector. Low-emission resources such as wind, solar, and biomass have significant expansion potential, but usable energy production is limited. Ignoring these limits can lead to unrealistic over-allocation under infrastructure constraints. In multiple-resource targeting without resource flow limits, irreplaceable resources with low-prioritized costs tend to be used excessively. This highlights the need to incorporate supply limits on resource flow into energy sector planning. This paper proposes a methodology for targeting multiple resources with supply limits by combining replacement and prioritized cost conditions. The methodology is demonstrated through Indian electricity and bioethanol sector planning for 2030. In the carbon-constrained electricity sector, planning wind, solar, and biomass are considered as resources and aim to minimize the Land Utilization Intensity of energy (LUIE) associated with them. The electricity sector planning results showed 100% utilization of the under-construction biomass (15 GW), 14.6% for solar, and no requirement for wind. In the bioethanol sector, this resulted in 100% utilization of available sorghum for bioethanol production and 24.07% utilization of wheat straw for the same.

Keywords: Energy sector planning; Resource Conservation Networks; Multiple resources; Indian energy sector 2030; Indian electricity and bioethanol sectors.

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Effect of UV degradation on the Material Characterization and Mechanical Performance of Recycled PET Bottle Filament for Fused Filament Fabrication

Mohammad Ashraf Nursal[1], Amzar Muaz Abdullah Sani[1], Norazimah Duraman[2], Hazimah Mahmud[1], Muhammad Saifullah Abu Bakar[1], Muhammad Mu'az Imran[1]*

[1] Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong BE 1410, Brunei Darussalam

[2] Applied Physics, Faculty of Science, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong BE 1410, Brunei Darussalam

Corresponding Author: muaz.imran@ubd.edu.bn

ABSTRACT

Global plastic accumulation drives the need for sustainable recycling, positioning recycled Polyethylene Terephthalate (rPET) as a viable feedstock for Fused Filament Fabrication (FFF). However, the material integrity of rPET filaments remains inconsistent due to cumulative thermo-mechanical processing and environmental Ultraviolet (UV) degradation. This study investigates the mechanisms of UV-induced degradation on the chemical, thermal, and mechanical properties of rPET 3D-printing filaments. Using a Taguchi L9 experimental design, discarded PET bottles were collected, washed, dried, exposed to UV radiation for 0, 7, and 14 days, then cut into strips and extruded into filaments at 250°C, 255°C, and 260°C. Characterization was performed via Fourier Transform Infrared (FTIR) spectroscopy, Thermogravimetric Analysis (TGA), Differential Scanning Calorimetry (DSC), optical microscopy, tensile and flexural testing. FTIR confirmed photo-oxidative chain scission, with the carbonyl index increasing from 5.641 (0 days) to 6.283 (14 days). TGA demonstrated thermal stability up to 400°C, leaving a 12%–22% residual mass. DSC thermograms identified a glass transition temperature (T_g) at approximately 79.43°C and a melting point (T_m) at 249.73°C, with shifted cold crystallization regions indicating altered molecular mobility and crystallinity. Mechanical testing showed that tensile and flexural performance varied with UV exposure and extrusion temperature, reflecting the combined influence of molecular degradation, crystallinity changes, and print-related defects. Optical microscopy revealed surface irregularities and interlayer delamination, explaining the observed scatter in mechanical properties. Overall, rPET shows promise as a sustainable FFF material, but reliable industrial application requires improved filament dimensional control and optimized thermal processing parameters.

Keywords: Additive manufacturing; polyethylene terephthalate (PET); plastic waste upcycling; material characterization; UV ageing

MSLA-Fabricated PEGDA-HEMA/Chitosan Hybrid Monoliths for Efficient Congo Red Adsorption

Ashreen Norman[1], Voon-Loong Wong[2], Suganti Ramarad[1], Chien-Hwa Chong[3], Kean How Cheah[4], Tze Chuen Yap[1]

[1] School of Engineering and Physical Sciences, Heriot-Watt University Malaysia, 62200 Putrajaya, Wilayah Persekutuan, Putrajaya, Malaysia
[2] School of Energy and Chemical Engineering, Xiamen University Malaysia, Selangor Darul Ehsan 43900 Malaysia
[3] Department of Chemical and Environmental Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia, 43500 Semenyih, Selangor, Malaysia
[4] Department of Mechanical, Materials, and Manufacturing Engineering, Faculty of Science and Engineering, University of Nottingham Ningbo China, Ningbo, Zhejiang China

Corresponding Author: voonloong.wong@xmu.edu.my

ABSTRACT

The textile industry is a significant source of water pollution due to its intensive water consumption and the discharge of dye effluents into water bodies. Synthetic dyes are particularly concerning because of their toxicity, persistence, and potential adverse effects on environmental and human health. Among the available treatment strategies, adsorption remains one of the most effective and practical approaches for dye removal. In this work, resin-based 3D printing (3DP) was adopted as a sustainable platform for the fabrication of adsorbent materials. Biocompatible and environmentally friendly resins, 2-hydroxyethyl methacrylate (HEMA) and poly (ethylene glycol) diacrylate (PEGDA), were combined with the natural polysaccharide, chitosan to produce 3D hybrid composite monoliths. The PEGDA-HEMA/Chitosan hybrid monolith was fabricated via masked stereolithography (MSLA) and evaluated for Congo red (CR) removal under varying initial dye concentrations (10, 30, and 50 ppm), temperatures (30, 35, and 40 ˚C), and adsorbent dosages (1, 2, and 3 lattices). The experimental data were analyzed using Box–Behnken design (BBD) coupled with regression modelling to elucidate the effects of process variable on dye removal efficiency (R%). The model predicted an optimum removal of approximately 99% within four hours at 40 ˚C, using 3 lattices at an initial CR concentration of 50 ppm. The adsorption process was found to be favored at elevated temperature, suggesting enhanced interaction between dye molecules and the adsorbent surface. Likewise, increasing adsorbent dosages improved R% owing to the greater availability of binding sites. The integration of chitosan with photocurable resin components demonstrates how 3DP can bridge material functionality with sustainable designs. Overall, this study demonstrates the potential of resin-based 3DP for the scalable fabrication of tunable hybrid adsorbents and highlights its promise for advanced wastewater treatment applications.

Keywords: Additive Manufacturing; Adsorption; Polysaccharide; Biocompatible Resins; Sustainable.

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Comparative Process Simulation and Mass Balance Analysis of an Algae Bio-CCU System Integrated with Gas- and Coal-Fired Power Plants Using SuperPro Designer

Atikah Desa[1], Afifi Zainal[1], Azuan Abdul Latif[1], Noraziah Muda[1]

[1] TNB Research Sdn. Bhd, Malaysia

Corresponding Author: nuratikah.desa@tnb.com.my

ABSTRACT

Transitioning fossil-fuel power generation toward net-zero emissions requires scalable and scientifically robust carbon capture solutions. While microalgae cultivation offers a promising biological pathway for carbon capture and utilisation (Bio-CCU), system efficiency is fundamentally dictated by the chemical composition of the incoming flue gas. This study models and compares the technical performance, mass balances, and total biomass yield of an Algae Bio-CCU facility linked to two distinct energy sources natural gas-fired power plant and a coal-fired power plant.

To reflect real on-site conditions, the process simulation is executed using SuperPro Designer across a defined cradle-to-gate boundary. The model encompasses flue gas conditioning, CO_2 delivery, and cultivation within seawater-based air-lift photobioreactors, supported by a tiered biokinetic framework that dynamically evaluates growth rates and carbon fixation efficiencies. Downstream processing is evaluated using a standardised harvesting and dewatering train, incorporating flocculation-sedimentation, high-speed centrifugation, and thermal drying technologies. By evaluating rigorous mass and energy balances, this study directly contrasts system responses between the two divergent flue gas streams.

The simulation quantitatively compares daily biomass productivity (kg/day), overall carbon assimilation rates, seawater and nutrient demands, and the downstream processing impacts of differing combustion profiles—specifically evaluating cleaner, lower-CO_2 natural gas emissions against higher CO_2, impurity-laden coal emissions. Grounded in realistic utility parameters, this comparative analysis provides engineers and industry stakeholders with the critical baseline data, equipment sizing requirements, and process optimization strategies necessary for deploying algae carbon capture systems across transitioning power generation fleets.

Keywords: Algae Bio-CCU; SuperPro Designer; Flue gas valorisation; Mass balance, Photobioreactors; Power plant emissions

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Co-digestion of Rabbit Manure with Food Waste for Biogas Production in Anaerobic Batch Digestion Process

Ayu Haslija Abu Bakar [1], Shiou Munn Lee[2], Nur Muhammad Afifi Zainal[3]

[1] School of Engineering, Faculty of Engineering and Technology, Sunway University, Malaysia

[2] Department of Chemical & Petroleum Engineering, Faculty of Engineering, Technology & Built Environment, UCSI University, Malaysia

[3] Department of Generation and Environment, Renewable Energy and Green Technology Unit, TNB Research Sdn. Bhd., Kajang, Malaysia

Corresponding Author: ayuhaslijaa@sunway.edu.my

ABSTRACT

Conventional energy sources such as fossil fuels are depleted with increasing greenhouse gas emission, contributing to global warming. Besides, population growth in Malaysia generates significant amount of organic waste, such as food waste and animal manure. Pollution threat to the environment may be posed if the waste is not handled properly. Anaerobic digestion is one of the approaches to mitigate the concerns mentioned above. Mono- and co-digestion of food waste (FW) and rabbit manure (RM) had been studied to evaluate the performance of the digestion process in terms of maximum biogas production, removal efficiency of total solid and volatile solid, and quantitative analysis such as specific biogas production (SBP) and gas production rate (GPR). In this study, four digester setups were operated in batch mode at 25℃ over 16 days. The digester setups were fed with FW and RM at ratios of 1:0 (A), 0:1 (B), 1:1 (C) and 2:1 (D) with constant inoculum to substrate ratio of 3. Results indicated that biogas production was enhanced in co-digestion, with an optimum FW to RM ratio of 2. Digester D was proved to be economical favorable due to the highest GPR obtained. Operating D at 35°C had demonstrated social and economic benefits in Malaysia's hot climate, as it has potential to double the biogas production. D also exhibited the highest removal efficiency of total solid and volatile solid (20.90% and 33.08%, respectively). Overall, the co-digestion of FW and RM had demonstrated a positive synergism effect in biogas production.

Keywords: Food waste; Rabbit manure; Co-digestion; Biogas; Renewable Energy

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A Review of Methane Yield from Anaerobic Digestion of Food Waste in Tropical Asia

Chong Zhao Jer[1], Chan Yi Jing[2]

[1] Department of Chemical Engineering, University of Nottingham, Malaysia

Corresponding Author: Yi-Jing.Chan@nottingham.edu.my

ABSTRACT

Food waste constitutes more than 40% of municipal solid waste in tropical Asian countries. This high biodegradable fraction represents both an environmental burden and a resource recovery opportunity. Anaerobic digestion (AD) provides a pathway to convert food waste into methane-rich biogas. However, reported methane yields vary widely across studies, suggesting that AD performance is governed not only by substrate characteristics but also by the interaction of operational conditions.

This review evaluates methane production from food waste AD under tropical conditions, based on studies published between 2019 and 2025. Key operational parameters affecting methane yield are examined, including feed-to-inoculum ratio, organic loading rate, hydraulic retention time, temperature, pH, mixing, and reactor configuration. Across the reviewed studies, methane yield generally ranges from 350 to 450 mL CH_4 g^{-1} VS, reflecting variations in system design and operation. Reactor performance has been assessed using several configurations, including batch reactors, continuous stirred tank reactors (CSTR), upflow anaerobic sludge blanket (UASB), anaerobic sequencing batch reactors (ASBR), and two-stage digestion systems.

Among these, thermophilic CSTR operating at 50–55°C has been reported to achieve the highest methane yields, reaching up to 450 mL CH_4 g^{-1} VS. This is attributed to enhanced hydrolysis at elevated temperatures and effective mixing, which ensures uniform substrate distribution. In addition, thermophilic digestion improves pathogen reduction and can be applied to various substrates, such as food waste, agricultural residues, and organic industrial wastes. However, these advantages must be balanced against higher energy demand and increased process sensitivity, which may reduce net benefits without proper integration of energy recovery.

Overall, AD is a viable technology for methane recovery in tropical Asia. However, maximising performance requires a systems-level approach that considers the interaction of operational parameters, reactor design, and energy balance. Future work should focus on integrated optimisation and process stability to support large-scale implementation.

Keywords: Anaerobic digestion; food waste; methane yield; operational parameters; tropical applications

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Oil Palm Bioenergy in Malaysia's National Energy Transition Roadmap: A Fuel Diversification Approach for Climate Resilience

Clarence Yii Fang Lau[1], Bing Shen How[1], Irene Moser[2], Viknesh Andiappan[1]

[1] Faculty of Engineering, Computing and Science, Swinburne University of Technology Sarawak, Malaysia

[2] School of Software, Computing and Emerging Technologies, Swinburne University of Technology, Melbourne, Australia

Corresponding Author: vmurugappan@swinburne.edu.my

ABSTRACT

Malaysia's energy transition, guided by the National Energy Transition Roadmap (NETR), targets net-zero emissions by 2050 through a gradual shift from fossil fuels to low-carbon energy sources. However, this transition is occurring amid escalating climate risks that increasingly threaten the resilience of electricity generation. Rising temperatures and shifting rainfall patterns are increasing the severity and frequency of extreme climate events, exposing vulnerabilities in Malaysia's energy system. Therefore, strengthening energy resilience alongside decarbonisation has become a national priority. Malaysia's palm oil sector generates large volumes of biomass residues that remain underutilised for domestic energy generation due to their high export value. This bioenergy resource shows significant potential to diversify the national energy mix while supporting decarbonisation objectives. Accordingly, this work evaluates how increasing the utilisation of oil palm-based bioenergy within the national energy mix can improve generation resilience while supporting NETR objectives. A multi-scenario energy planning model is developed to evaluate NETR energy mix under both normal operating conditions and a range of extreme climate scenarios (i.e., heatwaves, droughts, wildfires, storms and flooding). The model incorporates diversification metrics (i.e., Herfindahl-Hirschman and Shannon-Wiener indices) alongside a generation resilience index to assess the balance between system costs, feed diversification and generation resilience. An optimal energy mix is then identified based on these criteria. The analysis identifies oil palm-based bioenergy as a key contributor to a cost-effective and climate-resilient energy mix, alongside solar and hydropower. The results indicate that improving resilience is driven primarily by rebalancing the generation shares away from dominant fuels. Compared with NETR proposals, bioenergy increases from 1% to 21%, increasing overall generation resilience from 0.81 to 0.88. Overall, this work demonstrates that increased utilisation of oil palm-based bioenergy can enhance Malaysia's energy generation resilience while supporting NETR's objectives for a clean, sustainable and resilient energy future.

Keywords: Bioenergy utilisation, Climate-induced energy disruption, Energy generation resilience, Multi-scenario planning, National energy policy

Bioelectricity Generation from Fruit Waste in a Dual-Chamber Microbial Fuel Cell

Ee Ling Koh[1], Hui San Thiam[1], Siew Hoong Shuit[1], Gulnaziya Issabayeva[1], Kok Chung Chong[1], Soon Onn Lai[1]

[1] Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Malaysia

Corresponding Author: thiamhs@utar.edu.my

ABSTRACT

Fruit waste is highly biodegradable and prone to rapid spoilage, which can lead to odor generation, greenhouse gas emissions, and environmental pollution if not properly managed. This study explores a sustainable approach for bioelectricity generation by using fruit waste as a substrate in a dual-chamber microbial fuel cell (MFC). *Shewanella oneidensis* inoculum densities and organic substrate concentrations, expressed as chemical oxygen demand (COD) were varied to assess their impact on power density and COD removal efficiency. The anode chamber was inoculated with *Shewanella oneidensis* and fed with fermented fruit broth as the substrate. The cathode chamber contains deionized water and was continually aerated to enhance air supply. The findings indicate that a substate concentration of 5000 mg/L was optimal for system performance, while higher concentrations resulted in reduced efficiency due to substrate inhibition and mass transfer limitations. At this optimum concentration, the MFC achieved a COD removal efficiency of 70% and a maximum power density of 14.25 mW/m^2. In addition, an optimal bacterial density (OD = 0.4) enhanced electron transfer and biofilm activity. However, excessive inoculum led to competition for nutrients and reduced system efficiency. These results emphasize the importance of reactor design and suggest that MFCs could serve as a viable technology for converting fruit waste into bioenergy.

Keywords: Microbial fuel cell; *Shewanella oneidensis;* COD; Bioelectricity generation; Fruit waste

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Rapid and Precise Method for Microplastic Analysis in Malaysian Bottled Water

En Qi Lim[1], Hong Heng See[2,3*], Woei Jye Lau[1*], Pei Sean Goh[1], Michael C Breadmore[4], Haruka Takeuchi[5], Ahmad Fauzi Ismail[1]

[1] Advanced Membrane Technology Research Centre (AMTEC), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia.

[2] Centre for Sustainable Nanomaterials, Ibnu Sina Institute for Scientific and Industrial Research, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia.

[3] Department of Chemistry, Faculty of Science, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia.

[4] Australian Centre for Research on Separation Science (ACROSS), School of Natural Sciences, University of Tasmania, Hobart, Tasmania, 7001, Australia.

[5] Research Center for Environmental Quality Management, Kyoto University, Shiga 520-0811, Japan.

Corresponding Author: hhsee@utm.my (H.H. See); lwoeijye@utm.my (W.J. Lau)

ABSTRACT

Bottled water is widely consumed by the public, including in Malaysia. Increasing evidence indicates that it may contain microplastics (MPs), which can contribute to daily human exposure. In this study, eight different bottled water brands in Malaysia were analysed in triplicate (n=3) using an advanced, rapid and precise MPs identification technique — Laser Direct Infrared (LDIR) chemical imaging system. As the first LDIR-based investigation of bottled water in Malaysia, this work provides new regional data for Southeast Asia. Nine of the ten polymer types prioritized by the European Union (EU) were detected, with an average concentration of 28.14 MPs/L and a mean weight of 2.85 µg/L, most of them were under 30 µm in size. Frequently identified priority MPs included polyamide (PA), polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP) and polyurethane (PU). Apart from that, other particles such as natural polyamide, cellulose, chitin and rubber (dominant size: <50 µm) were also observed. While bottled water may not be the dominant MPs exposure pathway, the presence of small particles and plastic-associated chemicals warrants closer attention from regulators and public health authorities. These findings highlight the need for stricter water quality standards, comprehensive investigation into exposure pathways and effective mitigation strategies.

Keywords: Microplastics; Bottled water; Drinking water; LDIR

Functional Robustness of Multi-stimuli-responsive Self-repairing Polyethersulfone (PES) Membrane for Water Filtration

Eng Cheong Wong[1], Woon Chan Chong[2*], Yean Ling Pang[2], Ying Hui Ong[1]

[1] Department of Chemical Engineering, School of Engineering and Computing, MILA University, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia

[2] Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Sungai Long Campus, Jalan Sungai Long. Cheras 43000 Kajang, Selangor, Malaysia

Corresponding Author: chongwoonchan@gmail.com

ABSTRACT

Membrane technology offers an effective solution for clean water production, but its performance is often compromised by manufacturing defects and operational damage that are difficult to detect. These small flaws could lead to a premature failure and affect the membrane performance. Previously, a multi-stimuli-responsive (thermal and water) self-repairing polyethersulfone (PES) membrane was successfully fabricated via surface modification with polyethyleneimine (PEI) and poly(acrylic acid) (PAA), incorporating amine-functionalized carbon quantum dots (NCQDs) through the electrostatic layer-by-layer (LbL) method. In this study, the damage-tolerance capability of the fabricated membrane was evaluated by assessing its functional robustness and restoration in terms of pure water flux (PWF), self-healing effectiveness, solute rejection and rejection recovery. The membrane performance was compared between different cut numbers at the same location of the membrane under healing in distilled water at 60 °C for 24 hours. From the study, the membrane exhibited 97% recovery in PWF and 70% recovery in rejection after three cutting-healing cycles. The recovery in PWF was corroborated by the PWF analysis, which showed a relatively consistent flux of 37 $L/m^2.h$ across the first to third healing cycles. Meanwhile, solute rejection reached about 80 % in the first three healing cycles. In addition, the membrane surface topography using a scanning electron microscope (SEM) further visualized the healing performance. This observed healing performance is attributed to the intrinsic self-healing mechanism whereby hydrogen bonds at the cut region are reformed and facilitated by the chain mobility. These findings highlight the critical role of reversible hydrogen bond interaction in restoring the membrane structural integrity and functionality after damage.

Keywords: Intrinsic Self-repairing; Multi-stimuli; Water filtration; Physical damage; Damage-tolerance

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A Statistically Informed Machine Learning Framework for Robust Air Quality Forecasting

Tan Xin Ming[1], Nishanth Gopalakrishnan Chemmangattuvalappil[1], Samsuri Abdullah[2], Hayana Dullah[1*] and Ali Najah Ahmed[1]

[1] Faculty of Engineering and Technology, Sunway University, 5, Jalan University, Bandar Sunway, 47500 Petaling Jaya, Selangor
[2] Faculty of Ocean Engineering Technology, Universiti Malaya Terengganu (UMT), 21030 Kuala Terengganu, Terengganu

**Corresponding Author: hayanad@sunway.edu.my*

ABSTRACT

Reliable air quality forecasting remains a practical challenge due to the highly dynamic, nonlinear and pollutant-specific behaviour of atmospheric systems. In many studies, machine learning models are applied directly to data without sufficiently understanding the statistical structure that governs pollutant variability. This study presents a statistically informed machine learning framework that integrates time-series diagnostics with predictive modelling to improve forecasting reliability and interpretability. Hourly air quality data collected between July and September 2025 at Taman Botani, Kuala Terengganu, Malaysia, were analysed for six pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), particulate matter smaller than 2.5 micrometres ($PM_{2.5}$) and 10 micrometres (PM_{10}). Statistical profiling, including stationarity testing, autocorrelation assessment, persistence analysis and multicollinearity evaluation, was first conducted to understand pollutant behaviour and guide preprocessing strategies. Two predictive models, Long Short-Term Memory (LSTM) networks and Extreme Gradient Boosting (XGBoost), were then developed using both baseline interpolation and a processed dataset incorporating Hampel filtering with 24-hour lag replacement. The processed dataset markedly improved particulate matter prediction, with XGBoost achieving coefficient of determination (R^2) values close to 0.95 for PM2.5 and PM10. However, SO_2 performance deteriorated after preprocessing due to sparse concentration patterns, while the non-stationary characteristics of NO_2 affected LSTM stability. Noise stress-testing further highlighted differences in model robustness, with moderate perturbations improving CO prediction under LSTM. Overall, the findings demonstrate that embedding statistical understanding within machine learning workflows strengthens forecasting performance and provides a more structured pathway toward intelligent environmental monitoring in chemical and environmental engineering applications.

Keywords: Air quality forecasting, Machine learning, Statistical diagnostics, XGBoost, LSTM

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Establishing the Economic Value of Empty Fruit Bunch to Inform Valorisation Pathways in Palm Oil Mills

Hemavathi Silvamany[1], Tan Bee Aik[1], Kumaran Rajagopal[2] , Muhammad Ainuddin Ubaidah[3], Muhamad Faiz Rezali[3], Nur Fadhilah Ikhsan[3]

[1] Mill Research, Upstream Research, SD Guthrie Research Sdn Bhd, Malaysia

[2] Plantation Research & Advisory, Upstream Research, SD Guthrie Research Sdn Bhd, Malaysia

[3] Biomass Development & Project, SD Guthrie Renewable Energy Sdn Bhd, Malaysia

Corresponding Author: hemavathi.s@sdguthrie.com

ABSTRACT

Empty fruit bunch (EFB) is the largest biomass stream generated in palm oil milling and has attracted growing interest as a feedstock for commercial valorization into products such as biochar, energy pellets, and renewable electricity. Any evaluation of these options must first account for the value EFB already provides as a mulch, where it supports soil conditioning, nutrient recycling, and fresh fruit bunch (FFB) yield. This study establishes baseline and adopts it as the reference against which alternative conversion pathways are evaluated. The net value of mulching is determined on a per hectare and per tonne basis from three components: the yield uplift from field validated FFB response, the fertilizer displacement achieved through reduced muriate of potash (MOP) and rock phosphate (RP) application, and the associated evacuation, transport, and field application costs. The analysis yields a net mulching value of RM27 per tonne on inland estates and RM10 per tonne on coastal estates, a 2.7 times difference attributable to soil yield response. Further gains on inland estates are achievable by maximizing the MOP and RP fertilizer offset, with prolonged application also indicating potential for reduced nitrogen input over time. On coastal and peat estates, where an accessible EFB surplus exists, commercial valorization presents the more favorable option. The mulching baseline was subsequently benchmarked against five valorization pathways, namely biochar, renewable electricity, energy pellets, pulp and molded fibre, and wood products, under own investment and build own operate transfer models. Under prevailing market and carbon pricing conditions, mulching remains the highest value use of EFB, while the analysis identifies the thresholds of carbon credit maturity, offtake certainty, and feedstock scale at which valorization of the coastal and peat surplus becomes economically competitive. The resulting replacement value approach provides a practical decision support tool that quantifies the true worth of EFB and defines the conditions under which valorization can be pursued at scale.

Keywords: EFB replacement value, Biomass valorization, Mulching economics, Fertilizer offset, Palm oil milling

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Supply-Reduction Optimization and Resource Allocation in Net Zero Industrial Complexes

James David A. Abiog[1], Mac Joseph B. Rosales[1], Guada Altea Erin M. Layugan[1], Raymond R. Tan[1,2], John Frederick D. Tapia[1,2], Kathleen B. Aviso[1,2]

[1] Center for Engineering & Sustainable Development Research, De La Salle University, 2401 Taft Avenue, 0922 Manila, Philippines
[2] Department of Chemical Engineering, De La Salle University, 2401 Taft Avenue, 0922 Manila, Philippines

Corresponding Author: james.abiog@dlsu.edu.ph

ABSTRACT

Net-zero industrial complexes rely on highly coupled material and energy exchanges between component facilities. This rigid operational interdependence exposes the network to upstream vulnerabilities. Such supply-side disruptions frequently arise from climate change-induced extreme weather events, which can lead to disruption in the supply of critical resources, such as water or renewable power, required by the industrial complex. This work applies an optimization-driven enterprise input-output (EIO) model to manage these capacity constraints. The embedded mixed-integer linear programming (MILP) formulation dictates the optimal intra-complex rationing of limited resources, minimizing the aggregate fractional production loss of the cluster. The resulting optimal allocation profiles provide decision-makers with quantitative strategies to mitigate cascading operational bottlenecks. To validate the proposed framework, the model is applied on an interdependent, six-node net-zero industrial complex. The conceptual case study evaluates the optimal allocation of renewable energy and conditioned resources to sustain an electrofuels refinery and a geological carbon storage site.

Keywords: Net-Zero; Resource allocation; Supply chain disruption; Systemic resilience; Carbon storage

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Predicting the Formation of Room-Temperature Liquid Deep Eutectic Solvents using Interpretable Rough Set Machine Learning

Ji Hin – Shawn Tan[1], Nishanth G. Chemmangattuvalappil[2], Kiat Moon Lee[3], Jecksin Ooi[1]*

[1] School of Engineering and Physical Sciences, Heriot-Watt University Malaysia, Jalan Venna P5/2, Precinct 5, 62200 Wilayah Persekutuan Putrajaya, Malaysia
[2] School of Engineering, Research Centre for Carbon Dioxide Capture and Utilisation (CCDCU), Faculty of Engineering and Technology, Sunway University, Jalan University, Bandar Sunway, 47500 Petaling Jaya, Selangor, Malaysia
[3] Department of Chemical & Petroleum Engineering, Faculty of Engineering, Technology and Built Environment, UCSI University, 56000 Kuala Lumpur, Malaysia

Corresponding Author: j.ooi@hw.ac.uk

ABSTRACT

Deep eutectic solvents (DESs) have emerged as a transformative class of green solvents, offering sustainable alternatives to traditional volatile organic compounds for various industrial applications due to their tunable physicochemical properties. To maximise their application, the rational design of DESs that remain liquid at room temperature is essential. DESs are formed by combining hydrogen bond acceptor (HBA) with hydrogen bond donor (HBD) at a specific molar ratio, leading to a deep melting point depression. This phenomenon is driven by the thermodynamic destabilisation of the crystal lattice through complex intermolecular interactions, primarily hydrogen bonding. However, a significant knowledge gap exists as most current research focuses solely on the high accuracy prediction of numerical melting points for applications; the underlying chemical mechanisms and the fundamental reasons for liquidity largely unexplored. Existing models function as “black boxes”, providing predictive values for the melting points of DESs without offering interpretability regarding the molecular drivers of formation. In this work, rough set machine learning (RSML) is used to develop a transparent interpretable model for identifying the formation of liquid-state DESs at room temperature. The study utilises an information system of conditional attributes including the HBD’s melting points, molar ratio, halide types and difference in molecular weight (ΔMW), while the decision attributes are the formation of alcohol-based DESs and the state of DESs at room temperature. The methodology involves constructing a dataset from literature, partitioned into 70% training and 30% validation sets. By using the transparent “if-then” decision rules generated by RSML, the conditions required for liquidity are quantified. The model identifies HBA/HBD ratio as the core for both decisions, with lower ratios significantly favouring stable liquid formation. Specifically, chloride-based HBAs with aliphatic chains paired with low-melting HBDs are expected to form stable liquid. Conversely, extreme ΔMW is identified as a critical constraint that prevents effective eutectic formation.

Keywords: Deep Eutectic Solvents (DESs); Room Temperature DESs; Rough Set Machine Learning

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Development and Experimental Study of an Alginate-Based Hydrogel Agent for Extinguishing Class A and Class B Fires

Jerell Shi Heng Hoh[1,2], Wai Fen Yong[1,2,3]

[1] School of Energy and Chemical Engineering, Xiamen University Malaysia, Selangor Darul Ehsan 43900, Malaysia

[2] Centre of Excellence for Green and Advanced Technologies in Efficient Separations (GATES), Xiamen University Malaysia, Selangor Darul Ehsan 43900, Malaysia

[3] State Key Laboratory of Physical Chemistry of Solid Surfaces, College of Chemistry and Chemical Engineering, Xiamen University, Xiamen 361005, China

Corresponding Author: waifen.yong@xmu.edu.my

ABSTRACT

Hydrogels are three-dimensional polymeric structures capable of retaining large amounts of water, and have shown potential for fire suppression due to their reduced vaporization rate and ability to form protective coating layers. Among these materials, alginate-based hydrogels are particularly promising due to their ease of fabrication, low toxicity, and biodegradability. In this study, alginate-based hydrogels were developed via ionic cross-linking between sodium alginate and calcium chloride, with the incorporation of alkali-metal salts as fire retardant additives to further improve performance. Fire suppression performance was evaluated using Class A and Class B fire experiments, alongside fire retardancy tests. Compared to water, the hydrogel extinguishants exhibited significantly improved performances against Class A and Class B fires, reducing extinguishing times by up to 75.0% and consumption dosages by 92.8%. In addition, the developed agent exhibited strong retardant behavior, delaying ignition up to 93.3%. Overall, this work presents a sustainable, low-impact and effective fire extinguishing agent.

Keywords: Fire extinguishing agent; Class A fire; Class B fire; Alginate-based hydrogel; Fire extinguishing efficiency

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Mechanistic Elucidation of Microbial Priming via Coupled Cybernetic and Population Balance Modelling of Organic Matter Degradation Dynamics

Joel Sun Ee Yow[1], Yong Kuen Ho[2], Zee Wei Lai[3], Yin Hui Chow[1,4], Firnaaz Ahamed[1,4,5*]

[1] School of Engineering, Faculty of Innovation & Technology, Taylor's University, Malaysia
[2] Department of Chemical Engineering, School of Engineering, Monash University Malaysia, Malaysia
[3] School of Biosciences, Faculty of Health & Medical Sciences, Taylor's University, Malaysia
[4] Food Security & Nutrition Impact Lab, Taylor's University, Malaysia
[5] Centre for Sustainable Societies, Taylor's University, Malaysia
**Corresponding Author: Firnaaz.Ahamed@taylors.edu.my*

ABSTRACT

Microbial priming is the alteration of basal decomposition rates of soil organic matter (OM) by minimal addition of external labile (readily bioavailable) OM which plays a critical role in ecological nutrient cycling and carbon sequestration. However, priming mechanisms and factors are complex, confounded, and difficult to isolate experimentally. Despite this, we hypothesize that priming is fundamentally driven by the microbial regulation of complex (polymeric) substrate degradation dynamics governed by chemical traits, particularly recalcitrance characterized by its degree of polymerization (DP) and polydispersity index (PDI). Existing priming studies predominantly focus on soil environments, making it difficult to ascertain the hypothesis due to the influence of biological factors, soil OM diversity, and other environmental factors. Meanwhile, existing computational models often simplify polymer degradation into lumped reactions, failing to account for the dynamics of distributed polymeric properties and the optimization strategies employed by microbes in response to varying OM properties. This research addresses the foregoing limitations by integrating cybernetic modelling (represents microbial regulation) with population balance modelling (captures the temporal evolution of distributed polymeric properties) into a comprehensive theoretical framework to elucidate the fundamental mechanisms underlying microbial priming. Here, we computationally examined the effects of OM recalcitrance and relative quantity of external labile OM on the magnitude and direction (positive or negative) of priming effects using Monte Carlo simulation. The priming was quantified by comparing each test case with a control without external labile OM. Overall, our results indicate that priming outcomes are highly dependent on the recalcitrance of complex OM, and that priming varies significantly with temporal changes in polymeric properties arising from degradation dynamics. By bridging the gap between evolving OM polymeric properties and microbial behavior, this study lays a robust framework for predicting carbon flux in natural ecosystems and engineered bioprocesses.

Keywords: Microbial priming; Cybernetic modelling; Population balance modelling; Organic matter recalcitrance; Distributed polymeric properties

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Palm Oil-Based Tocotrienols Double Emulsion Encapsulation Using Needle-Based Microfluidic Device

Koh Kai Seng[1], Aisyah Mohamad Sahari[1], Ren Yong[2], Fu Ju Yen[3], Lim Chang Nong[4]

[1] Department of Chemical Engineering, Heriot-Watt University, Malaysia

[2] Department of Mechanical, Material and Manufacturing Engineering, University of Nottingham Ningbo, China

[3] Product Development and Advisory Services Division, Malaysia Palm Oil Board, Bandar Baru Bangi, Malaysia

[4] Department of Chemical Environmental Engineering, University of Nottingham, United Kingdom.

Corresponding Author: k.koh@hw.ac.uk

ABSTRACT

Palm oil accounts for about 40% of all edible oils consumed worldwide. Palm oil-based tocotrienol is a form of vitamin E that can increase palm oil's value. Among the many benefits of tocotrienol supplementation is lowering cholesterol levels. Due to the limited technology currently available, most oleochemical companies in the nation do not offer tocotrienols in supplement form. Therefore, this research focuses on the encapsulation of a double emulsion of tocotrienol via a microfluidic approach in an oil-in-water-in-polymer (O/W/P) system. A needle-based microfluidic device is used, making the encapsulation cost-effective and reusable. Flowrate ratio studies for the device's upstream and downstream were performed to generate flow maps of the system and to investigate flowrate effects for each phase. Squeezing occurs only when the capillary number is low in upstream, and as the flowrate ratio increases, dripping takes over. Squeezing detachment is caused by a pressure drop from the buildup of dispersed phase fluid at the junction, while dripping is shear-driven. An increase in the flowrate of dispersed phase in upstream caused an increase in the core droplet size from 678 to 1825 μm, while an increase in the continuous phase flowrate reduced the size from 718 to 228 μm. The interfacial tension and pushing force from the continuous phase flow influence the downstream of the device, causing dripping and jetting regimes to occur, respectively. A higher continuous flowrate downstream produced larger double emulsion droplets, the largest of which contained 0.7 mm^3 tocotrienol in a 33 mm^3 shell.

Keywords: Tocotrienols; Double emulsion; Microfluidic; Supplements; Monodisperse

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Sustainable Carbon Dioxide Capture from Flue Gas Using Ionic Liquids: Process Development and Performance Assessment

Kanti Kumar Athankar
Department of Chemical Engineering
IPS Academy, Institute of Engineering & Science, Indore 452012 (M.P.) India
Corresponding Author: drkantikumar@ipsacademy.org

ABSTRACT

The rapid increase in atmospheric carbon dioxide (CO_2) emissions has intensified the need for efficient and sustainable carbon capture technologies. Conventional amine-based absorption systems, although commercially established, suffer from limitations such as solvent degradation, high regeneration energy requirements, and corrosion issues. In this context, ionic liquids (ILs) have emerged as promising alternatives due to their negligible vapour pressure, high thermal stability, tunable physicochemical properties, and enhanced CO_2 selectivity.

This study presents a comparative assessment of ionic liquid-based systems for post-combustion CO_2 capture from flue gas with emphasis on process development and sustainability considerations. Different classes of ILs, including amine-functionalized, fluorinated, and task-specific ionic liquids, were evaluated based on CO_2 absorption capacity, selectivity, reaction kinetics, regeneration efficiency, thermal stability, and operational feasibility. Particular attention was given to the influence of cation–anion interactions and functional group modifications on CO_2 capture performance. In addition, recent developments in supported ionic liquid systems, membrane-assisted separations, and hybrid absorption technologies were analysed to assess their potential for process intensification and industrial implementation.

The assessment indicates that IL-based systems exhibit significant potential for sustainable CO_2 capture due to improved absorption characteristics and reduced solvent losses compared with conventional absorbents. However, challenges associated with high viscosity, cost, and scale-up remain important barriers to large-scale deployment. The findings provide insights into the design and development of next-generation ionic liquid systems for environmentally sustainable carbon capture applications.

Keywords: Carbon dioxide capture; Ionic liquids; Flue gas treatment; Process development; Sustainable separation.

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Rainwater Harvesting and Smart Water Treatment Integration in a Tropical Net-Zero Carbon Building: A Living Laboratory Case Study at Sunway University

Karen Gah Hie Kong*[1], Dalila Alias[1], Lewis Jen Looi Tee[1], Denny K. S. Ng[1]

[1] Faculty of Engineering and Technology, Sunway University, Malaysia

Corresponding Author: karenkong@sunway.edu.my

ABSTRACT

Rainwater harvesting represents a strategic pathway for tropical urban buildings to advance net-zero and low-carbon development. By reducing reliance on centralized treated water, improving water-use efficiency, and enhancing on-site resource resilience, such systems contribute directly to sustainable infrastructure goals. This paper presents the design and integration of a rainwater harvesting and smart water treatment system implemented in Sunway University's Net-Zero Carbon Building in Malaysia. Developed as a living laboratory, the system supports demonstration, research, and educational activities in tropical sustainable infrastructure. The study evaluates the contribution of building-integrated rainwater systems to net-zero objectives through a water–energy–carbon nexus perspective, while simultaneously meeting functional non-potable water demands. The system incorporates rooftop rainwater collection, first-flush diversion, storage, filtration and treatment units and sensor-enabled monitoring for operational tracking and maintenance. A building-scale demand–supply matching framework is employed to assess rainwater utilisation potential under tropical rainfall variability. System performance is further evaluated in terms of treatment efficiency, operational reliability, and integration requirements within building services. On the other hand, indirect carbon reduction potential is assessed by comparing avoided centralised treated water consumption with the operational energy needs of pumping, monitoring and treatment processes. The integrated system supports laboratories, studios, and classrooms, enabling real-world teaching, research, and stakeholder engagement on sustainable water infrastructure. The findings demonstrate that digitally integrated rainwater harvesting system not only plays a role in water conservation strategy but also as a complementary decarbonisation measure within tropical net-zero building development. The proposed framework provides practical insights for universities and urban buildings seeking to implement low-carbon, resilient, and resource-efficient water systems.

Keywords: Rainwater harvesting system; Net zero emissions, Tropical net zero building, Sustainable technologies

Three-Dimensional Graphene Oxide Composite for Zinc-Nickel Adsorption

Eve Qin Yi Lai, Jason Teck Zeng Wong, Nicholas Yung Li Loh, Suyin Gan, Lai Yee Lee*

Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, 43500 Semenyih, Selangor, Malaysia

**Corresponding Author: lai-yee.lee@nottingham.edu.my*

ABSTRACT

Heavy metal contamination in wastewater often involves the presence of multiple metals, such as zinc and nickel, which can increase overall toxicity. In this study, a three-dimensional (3D) graphene oxide composite was prepared to tackle this issue. Characterisation studies revealed a highly porous nanomaterial enriched with oxygen-containing functional groups. Response surface methodology was applied to optimise adsorption conditions. The adsorption equilibrium data were best described by the Extended Freundlich isotherm, highlighting adsorption on heterogeneous surfaces, while kinetic studies indicated pseudo-second-order behaviour consistent with chemisorption. Mechanism anaylsis showed that adsorption occurred through ionic exchange with the oxygenated groups, with zinc showing stronger uptake than nickel. This preference was due to zinc's smaller hydrated ionic radius and stronger affinity for oxygen donor groups, which allowed to bind more effectively to active sites. Regeneration studies using hydrochloric acid demonstrated effective desorption and confirmed the material's reusability. This study establishes the 3D graphene oxide composite as a practical adsorbent for treating wastewater containing multiple heavy metals.

Keywords: Adsorption; Graphene oxide; Nickel; Zinc; Wastewater

Application of Graphene Oxide Aerogel for the Continuous Removal of Iron and Aluminium

Nicholas Yung Li Loh, Suchithra Thangalazhy Gopakumar, Suyin Gan, Lai Yee Lee*

Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, 43500 Semenyih, Selangor, Malaysia

**Corresponding Author: lai-yee.lee@nottingham.edu.my*

ABSTRACT

This research investigates the application of graphene oxide aerogel for the continuous removal of iron and aluminium in a continuous adsorption setup. Continuous column studies were executed by varying the bed heights, flowrates and influent concentrations. Prominent operating parameters including bed height, influent concentration and feed flowrate were found to significantly influence the breakthrough profiles. Increasing bed height enhanced column performance by extending both breakthrough and saturation times, whereas higher flowrates and influent concentrations reduced contact time, resulting in faster saturation. Fourier-transform-infrared spectroscopy and X-ray photoelectron spectroscopy studies verified surface complexation as the dominant mechanism which anchored metal ions to the adsorbent. The dynamic column data were correlated to the Thomas and Clark models, as well as their fractal-like counterparts. The findings from the continuous packed-bed studies supported the use of graphene oxide aerogel for the effective remediation of metals in aqueous environment.

Keywords: Continuous adsorption; Graphene oxide aerogel; Surface complexation; Heavy metal remediation.

Binary Adsorption of Calcium and Cobalt onto Porous Graphene-based Composite

Nicholas Yung Li Loh, Svenja Hanson, Suyin Gan, Lai Yee Lee*

Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, 43500 Semenyih, Selangor, Malaysia

**Corresponding Author: lai-yee.lee@nottingham.edu.my*

ABSTRACT

This study reports the successful synthesis of a porous graphene oxide composite via ice-templating process. The resulting composite was evaluated as an adsorbent for the decontamination of simulated heavy metal effluent containing binary mixtures of calcium and cobalt in batch adsorption systems. Operating parameters such as adsorbent dosage, initial concentration, solution pH and contact time were assayed, alongside the determination of adsorption kinetics and isotherm. Kinetic analysis revealed that both metals followed the pseudo-second-order model, consistent with single component systems. The interactive parameters were further examined using response surface methodology and adsorption optimisation was achieved through central composite design. Scanning electron microscopy, energy dispersive X-ray and Fourier-transform-infrared spectroscopy verified the successful synthesis of the composite and effective anchoring of metallic ions onto the adsorbent. Adsorption–desorption cycle studies demonstrated the reusability of the composite, supporting its potential application for efficient heavy metal remediation in aqueous environments.

Keywords: Binary adsorption; Graphene oxide composite; Calcium; Cobalt; Wastewater treatment.

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Effect of Salt and Sugar Additives on Okra Protein Functionality and Cake Hardness

Low Suk Khe[1], Tan Mei Ching[1], Chin Nyuk Ling[2]

[1] Department of Chemical Engineering, School of Energy and Chemical Engineering, Xiamen University Malaysia, Malaysia
[2] Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia

Corresponding Author: meiching.tan@xmu.edu.my

ABSTRACT

The demands for sustainable and allergen-free plant-based foods have continued to rise in baking industry today, driving the industry to explore alternative protein sources that can replace egg whites. Compared to animal-derived ingredients, plant proteins offer lower environmental impacts and greater sustainability. However, their application in bakery product is often limited by poor functional properties on solubility, emulsifying and foaming performance. Okra protein has shown potential to serve as a sustainable functional ingredient, yet limited studies have explored its application as egg white substitute in bakery product, particularly in the presence of additives such as salt and sugar. Thus, this study aimed to compare the functional properties (i.e. protein solubility, emulsifying activity index, and foaming capacity) of egg white, sole okra protein, okra protein with added salt, and okra protein with added sugar, as well as their effects on cake hardness. Overall, the addition of additives enhanced the functional properties of okra protein. Okra protein supplemented with salt showed an 8.61% increase in protein solubility, which contributed to an improvement in foaming capacity by 113.31% compared to sole okra protein. Meanwhile, okra protein with added sugar exhibited an increase in emulsifying activity index of 3.35% compared to sole okra protein and 31.2% compared to egg white protein. In addition, cakes prepared with okra protein, with or without additives, demonstrated lower hardness values, approximately 73–78% lower than those prepared with egg white protein. These findings indicate that additive-modified okra protein has strong potential as a sustainable and environmentally friendly alternative protein source for bakery applications.

Keywords: Okra protein; Salt additive; Sugar additive; Functional properties; Cake hardness

Demand-Reduction Inoperability Modelling in Net Zero Industrial Clusters

Mac Joseph B. Rosales[1,2], James David A. Abiog[1], Guada Altea Erin M. Layugan[1], Raymond Girard R. Tan[2], John Frederick D. Tapia[2], Kathleen B. Aviso[1,2]

[1]Center for Engineering and Sustainable Development Research, De La Salle University, Philippines

[2]Department of Chemical Engineering, De La Salle University, Philippines

Corresponding Author: mac.rosales@dlsu.edu.ph

ABSTRACT

Future carbon-neutral industrial clusters will entail tight integration of material and energy flows among components of the plants. The interdependencies caused by these linkages can make these clusters vulnerable to cascading failures triggered by disruptive events such as market shifts, natural disasters, or malicious attacks. This work applies demand-reduction inoperability analysis to such systems via enterprise input-output models. The model estimates the inoperability, or fractional production loss, of the component plants in an industrial cluster resulting from a drop in product demand caused by an external event. The resulting information can be used to develop risk management strategies. This methodology is demonstrated with a case study of a futuristic net zero industrial cluster consisting of a solar farm, a direct air capture plant, a geothermal plant, a water purification plant, an electro-fuels refinery, and a geological carbon storage site.

Keywords: Carbon-neutral Industry; Electro-fuels; Inoperability Input-Output Model (IIM); Net-Zero System; Carbon Storage

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Modeling Energy Trade-Offs Enables Prediction of Dynamic Switching of Metabolic States in the Polyhydroxyalkanoate Cycle of *Pseudomonas putida*

Marcelina Alexandra Wibowo[1], Yin Hui Chow[1,2], Yong Kuen Ho[3,4,5], Firnaaz Ahamed[1,2,6]

[1] School of Engineering, Faculty of Innovation and Technology, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia.

[2] Food Security & Nutrition Impact Lab, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia.

[3] Department of Chemical Engineering, School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor, Malaysia.

[4] Monash-Industry Plant Oils Research Laboratory, Monash University Malaysia, Jalan Lagoon Selatan, Bandar Sunway, 47500 Selangor, Malaysia.

[5] Centre for Net-Zero Technology, Monash University Malaysia, Jalan Lagoon Selatan, Bandar Sunway, 47500 Selangor, Malaysia.

[6] Centre for Sustainable Societies, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia.

Corresponding Author: firnaaz.ahamed@taylors.edu.my

ABSTRACT

Polyhydroxyalkanoates (PHAs) are valuable bioproducts used in bioplastics, biomedical applications, and agriculture. PHAs are mainly synthesized by microorganisms, with *Pseudomonas putida* being a promising PHA-producing strain. The PHA cycle involves simultaneous synthesis, *in vivo* accumulation, and degradation, dynamically regulated by microorganisms in response to stress conditions such as nutrient limitation. Existing studies mainly use constraint-based modeling (CBM) without regulatory mechanisms, while dynamic models apply phase-specific constraints to approximate metabolic switching between the PHA cycle and microbial growth. This limits understanding of regulatory energy trade-offs, hindering biotechnological applications, scale-up, and metabolic engineering. To address this, this study integrates CBM with dynamic cybernetic modeling (CM) to elucidate regulatory trade-offs between the PHA cycle and microbial growth. The CBM captures the metabolic reaction network, including the PHA cycle, while the CM represents dynamic regulation of the PHA cycle and microbial growth. In a case study using the genome-scale metabolic network iJN1462 for *P. putida* KT2440, our framework dynamically predicts metabolic switching between metabolic states involving PHA cycle process and microbial growth without discretizing process phases or imposing distinct constraints. Our model, validated against literature data under diverse metabolic conditions, provides mechanistic insight into the regulatory trade-offs governing the PHA cycle for predictive bioprocess design and optimization. Overall, integrating CBM and CM creates a robust framework for capturing energy trade-offs in microbial metabolism under different environmental conditions, with applications beyond PHA synthesis.

Keywords: Genome-scale metabolic model; Dynamic cybernetic modelling, Pseudomonas putida; Polyhydroxyalkanoate cycle; Regulatory energy trade-offs

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An Innovative Approach to Enhanced Oil Recovery from Oily Wastewater Using Coalescing Technology and Recycle Stream Integration

Georgii Borisov[1], Eunice Ong[1], Raymond Ooi[1], Dominic Foo[2], Lucas Callaghan[1], Paul Callaghan[1]

1. OLEOLOGY, Henderson, Western Australia.
2. University of Nottingham Malaysia, Selangor, Malaysia.

Corresponding Author: Eunice Ong, EOng@oleology.com.au

ABSTRACT

Oil removal from water in oil and gas facilities remains a significant challenge in the industry, particularly in meeting stringent effluent discharge limits and water re-injection specifications for reservoir or aquifer disposal. Conventional oil-in-water separation technologies often face limitations in separation efficiency, operational reliability, and carbon footprint. In many cases, the focus on achieving discharge compliance results in the loss of recoverable oil, leading to substantial “value leakage” and missed revenue opportunities over the lifecycle of an oil and gas asset.

This study aims to optimize the oil recovery efficiency of the MYCELX Advanced Coalescer (MAC) oil recovery unit through the implementation of a pre-coalescer filter integrated with a recycle stream to enhance oil droplet growth prior to entering the MAC system. The performance of the system was evaluated based on the inlet and outlet oil droplet size distribution across the pre-coalescer stage with and without recycle integration, followed by assessment of the overall oil removal efficiency. The incorporation of a recycle stream was observed to promote oil droplet agglomeration and improve phase separation efficiency, resulting in higher oil recovery and lower residual oil concentrations in the treated water. Experimental findings demonstrate that integrating a recycle stream at the pre-coalescer stage effectively increases oil droplet size, thereby enhancing downstream separation performance within the MAC unit. The study highlights the potential of this integrated coalescing approach as a sustainable and economically beneficial solution for industrial oil recovery and produced water treatment applications.

Keywords: Oily wastewater; Coalescence; Oil recovery; Recycle stream; Produced water

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Investigating the Impact of Initial Concentration and Cycle Frequency on the Efficiency of Progressive Freeze Concentration

How Chee Yang[1], Thayabharan Yanasergaran[2], Mazura Jusoh[3]

[1] Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor, Malaysia
[2] Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor, Malaysia
[3] Centre of Lipids Engineering and Applied Research (CLEAR), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

Corresponding Author: r-mazura@utm.my

ABSTRACT

The food industry relies on concentration techniques to facilitate the storage and transport of fruit juices while preserving heat-sensitive nutrients. Traditional thermal evaporation often compromises product quality and requires high energy input, whereas freeze concentration (FC) offers a non-thermal alternative that maintains nutritional integrity. This study aims to investigate the potential of a commercial ice-making machine utilizing cooled evaporative slots as a falling film freeze concentration (FFFC) system, which is a specific design of progressive freeze concentration (PFC). Glucose solutions, serving as fruit juice mimics, were subjected to experimental trials to evaluate separation efficiency under varying conditions. The approach involved manipulating the initial solution concentration from 4 to 14 degrees Brix (°Brix) and adjusting the number of freeze concentration cycles between 2 and 12, with each cycle lasting 20 minutes. Performance was quantified through the concentration factor (CF), effective partition coefficient (K), and solute recovery (Y). Results demonstrated that separation efficiency was highest at lower initial concentrations; specifically, at 4 °Brix, the system achieved a CF of 1.15, a K value of 0.381, and a Y value of 0.919. While increasing the number of cycles to 12 successfully raised the CF to 1.5082, it simultaneously led to increased solute entrapment, indicated by higher K and lower Y values, due to rising solution viscosity and freezing point depression. Qualitatively, lower concentrations produced clearer, thicker ice crystals compared to the cloudy, dendritic structures observed at higher solute levels. This research is significant as it demonstrates that accessible, low-cost commercial hardware can be effectively repurposed for chemical engineering processes. By advancing the understanding of FFFC parameters in readily available systems, this work informs the design of more efficient, energy-saving concentration processes for the food and beverage industry.

Keywords: Falling film freeze concentration; Progressive freeze concentration; Glucose solution; Ice making machine; Separation efficiency

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Assessing Component Cost Contributions in Emerging Technologies Using AHP

Mohamad Akmal Mohamad Zaki[1], Jecksin Ooi[1], Chun Hsion Lim[1*]

[1] School of Engineering and Physical Sciences, Heriot-Watt University Malaysia, 1, Jalan Venna P5/2, Precinct 5, 62200 Putrajaya, Malaysia

Corresponding Author: L.Chun_Hsion@hw.ac.uk

ABSTRACT

This study presents a methodology to quantify the relative cost contributions of key emerging technologies in Industry 4.0 (IR4) and Industry 5.0 (IR5) implementation, facilitating investment strategy during digital transformation initiatives. There are significant uncertainties in cost prediction for emerging technologies, which arise from rapid technological evolution, limited long-term data, market volatility, integration complexities, and variable adoption rates. The approach recognizes this gap and addresses it by integrating historical cost trend analysis with the Analytic Hierarchy Process (AHP), a structured multi-criteria decision-making technique. Five representative technologies were selected: drones, IoT sensors, digital twins, cloud computing services, and cobots. First, historical cost trends for the main components of each technology (e.g., hardware, software, integration, deployment, and maintenance) were compiled and analyzed from market reports, industry analyses, and vendor data. Next, AHP was applied to derive transparent, ratio-based priority weights for the cost contributions of these components within each technology. For each technology, a hierarchical structure was defined with the overall goal of relative cost contribution at the top and the specific components as the elements to be prioritized. A pairwise comparison matrix was constructed for the components of each technology, where judgments were informed directly by the historical cost ratios from the trend analysis, using Saaty's fundamental 1–9 scale, with reciprocals for inverse comparisons. The principal eigenvector of each pairwise comparison matrix was then computed to obtain the normalized priority weights, representing the proportional contribution of each component to the total implementation cost for that technology. This methodology based on historical trend analysis feeding into rigorous pairwise comparison from AHP, eigenvector prioritization, and consistency verification enables stakeholders to achieve transparent, data-driven quantification of cost structures.

Keywords: Analytic hierarchy process; Multi-criteria decision-making; Technology investment strategy; Industry 4.0; Industry 5.0

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Synthesis of Polymer Supported Catalyst: Polystyrene-Hydrazone-Nickel Complex as Catalyst for Carbon-Carbon Coupling Reaction

Nur Rahimah Said[1,2]*, Syafiq Hakimin Norisham[1], Norul Azilah Abdul Rahman[1], Najwa Asilah M. Shamsuddin[1]

[1] School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Cawangan Negeri Sembilan, Kampus Kuala Pilah, Negeri Sembilan, Malaysia
[2] RIG Coordination Chemistry, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
Corresponding Author: nurra1435@uitm.edu.my*

ABSTRACT

Polystyrene is widely employed as a polymer support in heterogeneous catalysis owing to its accessibility, mechanical robustness, chemical inertness, product selectivity, and facile functionalisation. In parallel, nickel catalysts, as cost-effective and environmentally sustainable alternatives to palladium, offer a promising system for carbon-carbon coupling reactions. This study reported the development of a new heterogeneous catalyst, namely a polymer-hydrazone-nickel complex (PS-Ni) for use in Suzuki and Heck carbon-carbon coupling reactions. The synthesis of the complex involves three key steps. First, chloromethylated polystyrene is functionalised to form aldehyde-functionalised polystyrene (PS-CHO). This is followed by reaction with 4-hydroxybenzyl hydrazide to yield a polystyrene-supported hydrazone ligand (PS-H(OH)). Subsequently, the ligand is coordinated with nickel(II) chloride to produce polystyrene-hydrazone-nickel complex (PS-Ni). The complex was characterised using Fourier-transform infrared (FTIR), Powder X-ray Diffraction (PXRD), and flame atomic absorption spectrometer (FAAS). FTIR analysis confirmed the presence of key functional groups PS-Ni, validating the successful formation of complex. Furthermore, FAAS and PXRD analyses confirmed the existence of nickel metal in the polymer matrix. The catalytic performance of PS-Ni was evaluated using gas chromatography with flame ionization detection (GC-FID). All reactions were conducted using 1.0 mmol% catalyst loading, potassium carbonate (K_2CO_3) as the base and N,N-dimethyacetamide (DMA) as the solvent at 165°C. Reaction conditions varied in times (1, 2, and 3 hours) for both Suzuki and Heck reactions. The highest conversion for the Suzuki reaction is 77.72% was achieved at 1 hour, while the Heck reaction reached a maximum conversion of 99.4% at 2 hours.

Keywords: Polystyrene; Heterogenous catalysis; Nickel(II) catalyst; Suzuki reaction; Heck Reaction

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Deep Eutectic Solvents as a Sustainable Platform for Synthesis of Magnetic Graphene Oxide–COF Adsorbent for Polycyclic Aromatic Hydrocarbons Adsorption

Nurul Imanina Zameran[1], Noorashikin Md Saleh[1]

[1] Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Malaysia

Corresponding Author: noorashikin@ukm.edu.my

ABSTRACT

Deep eutectic solvents (DESs) have emerged as sustainable alternatives to conventional organic solvents due to their low toxicity, tuneable properties, and environmental compatibility. Here, we report, for the first time, the DES-mediated synthesis of a magnetic graphene oxide–covalent organic framework adsorbent (MGO–COF–HDES) for enhanced polycyclic aromatic hydrocarbons (PAHs) removal from water. MGO was synthesized via co-precipitation, followed by in-situ formation of an imine-linked COF in a choline chloride–ethylene glycol DES, eliminating the use of hazardous solvents. Hydrophobic modification using a hydrophobic DES enhanced adsorption affinity toward hydrophobic PAHs. Structural characterization confirmed successful composite formation. FTIR spectra showed Fe–O, C=N, and hydrophobic functional group vibrations, while XRD verified Fe_3O_4 crystallinity and COF ordering. FESEM revealed morphological evolution from wrinkled MGO sheets to uniformly distributed spherical and granular nanoparticles anchored on graphene, indicating successful COF growth and reduced sheet restacking. BET analysis showed increased surface area (183.77 $m^2\ g^{-1}$) and pore volume (0.23 $cm^3\ g^{-1}$), confirming enhanced porosity. VSM analysis indicated sufficient magnetic responsiveness (saturation magnetization: 11.303 emu g^{-1}), enabling rapid magnetic separation. Adsorption studies using six representative PAHs (10–50 mg L^{-1}) showed concentration-dependent uptake, with equilibrium data best fitting the Freundlich model (R^2 = 0.53–0.96), indicating heterogeneous multilayer adsorption driven by hydrophobic and π–π interactions. Equilibrium was reached within 20 min, and kinetics followed a pseudo-second-order model (R^2 > 0.9948). Reusability tests conducted for five cycles showed high removal efficiencies (≈99.86–99.99%), declining moderately to ~70% after the third cycle. Application to real water matrices achieved 60.87–96.42% of PAH removal. These results demonstrate that DES-mediated synthesis can provides a sustainable and effective approach to fabricate magnetic graphene-based COF adsorbents with high porosity, rapid adsorption kinetics, and excellent reusability for PAH removal from aqueous systems.

Keywords: Deep eutectic solvents; Graphene oxide; Covalent organic frameworks; Adsorbent; Polycyclic aromatic hydrocarbons

Effect of Ionic Liquid–Functionalized Graphene Oxide Loading on CO_2 Separation Performance of Pebax Mixed Matrix Membranes

Jia Huei Ho, Peng Chee Tan*

School of Energy and Chemical Engineering, Xiamen University Malaysia, Jalan Sunsuria, Bandar Sunsuria, Sepang, Selangor Darul Ehsan 43900, Malaysia

Corresponding Author: pengchee.tan@xmu.edu.my

ABSTRACT

Graphene oxide (GO)/Pebax-1657 mixed matrix membranes (MMMs) have been well-recognized as a cost-effective solution for carbon capture. Nonetheless, their separation performance is often compromised by GO aggregation and the formation of interfacial voids. To overcome these challenges, this study focused on the development of ionic liquid functionalized GO (IL-GO) by covalently functionalizing GOs with 1-butyl-3-methylimidazolium bis(trifluoromethylsulfonyl)-imide ([BMIM][Tf2N]) ionic liquid (IL) via a two-steps approach. During the synthesis process, the lateral dimension of GO sheets, which was controlled under ultrasonic treatment ranging from 2-4 h, was found to affect the functionalization efficiency. Among the samples, the medium-sized GO (GO-M) exhibited the most stable properties, leading to the highest degree of functionalization in IL-GO-M. To further evaluate the fillers properties as well as the membrane morphologies, comprehensive analysis including FTIR, AFM and FESEM were carried out. The characterization results revealed that MMMs incorporating IL-GO-M (321 nm) showed the most homogeneous morphology with minimal particles aggregation compared to IL-GO-S (237 nm) and IL-GO-L (413 nm). The CO_2 separation performance of the MMMs incorporating with varying lateral sizes of IL-GOs was also examined across different loadings (0.02-2.0 wt.%). Notably, the 0.5 wt.% IL-GO-M/Pebax MMM demonstrated the most promising results, achieving a CO_2 permeability of 154.07 Barrer and a CO_2/CH_4 selectivity of 58.50, suggesting its strong potential for high-performance carbon capture applications.

Keywords: Graphene oxide; Lateral sizes; Functionalization; Ionic liquid; Mixed matrix membrane

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Experimental optimisation of post-combustion membrane contactor carbon dioxide capture- gas-in-tube vs gas-in-shell configuration

Hue Seng Hoe[1], Athirah Tamidi[1], Ayuni Shahira[1], Nur Amelia Deana[1]

[1] Petronas Research Sdn Bhd, Bangi, Selangor, Malaysia

Corresponding Author: hue.senghoe@gmail.com

ABSTRACT

Membrane contactor (MBC) technology has been successfully deployed at pilot stage level within Petronas for post-combustion carbon dioxide (CO_2) capture in 2025. MBC is a hybrid membrane-solvent technology that utilises porous membranes to increase the total contact area between the flue gas and the amine-based solvent, thereby increasing the mass transfer efficiency and reducing overall separation reactor size, when compared to traditional packed bed column. In order to achieve the required removal purity and flowrate, the flux of the system, defined as the rate of mass transfer per membrane area, must be defined accurately. In this paper, comparisons between the CO_2 removal using a 1.5m long membrane contactor with gas-in-shell and gas-in-tube configuration are presented. By considering the hydrophobic nature of the membrane and the diffusion and reaction kinetics between CO_2 and the solvent, we will explore the changes in the performance and how the resulting fluxes are affected. Optimisation through design of experiments (DoE) also showed the optimal cases for when each configuration is desired; a lower gas side pressure drops for gas-in-shell configuration while better removal for higher CO_2 concentrations for gas-in-tube configuration.

Keywords: Membrane contactor; CO_2 capture; Separation; Experimental optimization; Diffusion reaction

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Data-Driven Process Safety Analytics Using Multimodal Machine Learning on OSHA Severe Injury Reports

Aafiya Afsheen[1], Muthulakshmi Arumugasamy[1], Mimi H. Hassim[2], Senthil Kumar Arumugasamy[3]*

[1] Department of Computer Science and Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, 600119, India
[2] UTM-MPRC Institute for Oil and Gas / Safety and Health Research Group, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[3] Department of Chemical and Environmental Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia, 43500, Semenyih, Selangor, Malaysia
Corresponding Author: Senthil.Arumugasamy@nottingham.edu.my

ABSTRACT

The analysis of the occupational injuries is a crucial task in the advancement of industrial risk assessment and safety management. However, the sheer volume of the data and the unstructured nature of the narratives pose a challenge in the identification of the hazards. The OSHA Severe Injury dataset contains a set of structured features such as industry classification, injury type characteristics (nature of injury and part of body Injured), source of injury, and hospitalization status, along with a comprehensive set of narrative descriptions of the injuries. In this study, a comparative machine learning framework is proposed for the classification of different types of injury events based on the Occupational Safety and Health Administration (OSHA) dataset containing 99,000 incident reports. The text data was preprocessed using techniques such as normalization and tokenization, and the structured features are encoded and integrated into the model. The classification models used are the ensemble models such as Random Forest, Extreme Gradient Boosting (XGBoost), and Light Gradient Boosting Machine (LightGBM), and the Bidirectional Encoder Representations from Transformers (BERT) model was used for the classification of the narratives. The BERT model was also used in a hybrid framework with the features for the classification of the narratives. The models are evaluated based on the metrics such as accuracy, precision, recall, and F1-score for the class imbalance in the data. The results show the effectiveness of the BERT model in the classification of the narrative descriptions of the injuries compared to the application of the traditional machine learning models. In addition, the hybrid model performs the best in terms of classification accuracy by integrating the BERT model with the structured features. The proposed model is useful in the context of safety data and its application in the identification of hazards in the context of process safety.

Keywords: Process safety; OSHA incident reports; Machine learning; Natural language processing; Multimodal data fusion

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Fabrication of Alginate-Based Membrane with Antimicrobial Properties for Wound Healing Application

Zhi Ken Law[1], Qing Kai Chun[1], Ching Lik Hii[1], Siti Norazlin Muhamad Nor[2], Siew Shee Lim[1]

[1] Faculty of Science and Engineering, Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia.

[2] Faculty of Science and Engineering, School of Biosciences, University of Nottingham Malaysia, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia.

Corresponding Author: SiewShee.Lim@nottingham.edu.my

ABSTRACT

Sodium alginate is a biocompatible polymer widely used in wound dressings but its inherently low antimicrobial activity limits its clinical effectiveness. This study investigates the rapid fabrication of alginate-based silver nanoparticle (AgNP) membranes via microwave drying to enhance antimicrobial performance for wound healing applications. Silver nitrate served as the metal precursor, sodium alginate functioned as both stabilizing and reducing agent, and sodium hydroxide was used as a reaction accelerator. AgNP-loaded alginate membranes were synthesized through microwave heating at 300 W for 60 s, followed by drying at microwave power of 100, 180, and 300 W. The membranes were comprehensively characterized in terms of drying kinetics, effective moisture diffusivity, energy consumption, functional groups, macroscopic integrity, surface morphology, colour properties, and antimicrobial activity. Zeta sizer analysis confirmed successful AgNP formation with an average particle size of 73.52 nm. Effective moisture diffusivity increased with microwave power and the highest dehydration rate observed at 300 W. Compared to pure alginate membranes, AgNP-incorporated membranes exhibited lower activation energy (15.79 W g^{-1}), indicating improved drying efficiency. FTIR spectra showed similar functional groups for both membranes; peak broadening and reduced O–H stretching intensity indicated AgNP incorporation, while the absence of new peaks confirmed membrane purity. FESEM images revealed increased membrane fracturing at higher microwave power for both membrane types with localized AgNP aggregation. CIELAB color analysis demonstrated reduced lightness and increased yellowness at elevated power levels. Notably, antimicrobial activity of alginate-based AgNP membranes remained consistent across microwave powers, showing strong inhibition against Gram-negative bacteria, whereas pure alginate membranes were inactive. Overall, microwave drying offers a rapid and effective strategy for producing alginate-based AgNP membranes with enhanced antimicrobial properties for wound dressing applications.

Keywords: Alginate-based membranes; Antimicrobial properties; Drying kinetics; Microwave drying; silver nanoparticles

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Enhancement of Energy Efficiency for Chilled Water Networks in Existing University Building

Dalila Alias[1], Ong Hwai Chyuan[2], Philip Tan[3], Denny Ng[3]

[1] Faculty of Engineering and Technology, Sunway University, Malaysia

[2] Facilities Services Department, Sunway University, Malaysia

Corresponding Author: dalilaa@sunway.edu.my

ABSTRACT

Chilled water networks play a critical role in meeting the cooling demands of large buildings such as university campuses through heating, ventilation, and air conditioning (HVAC) systems. HVAC system accounts for 30 – 45% of total energy consumption in buildings. Aging facilities with legacy infrastructure, where inefficient equipment and lack of advanced control systems increase overall energy demand. This study investigates effective energy retrofit strategies aimed at enhancing the energy efficiency and performance of chilled water networks in existing university buildings. Three key systems were studied: cooling tower system, chiller plant and air distribution system. The retrofitting approaches were assessed through a combination of walkthrough activities to the site, detailed energy audits, simulation of chiller units using Aspen HYSYS and cost-benefit analysis to determine the technical and economic viability of each strategy. Preliminary results from this study indicate that improving chiller efficiency from 0.85 kW/tonR to 0.57kW/tonR through the application of advanced control strategy can result in 37.7% of energy cost savings, along with significant reductions in greenhouse gas emissions. The implementation of controls via a building management system (BMS), carrying out air balancing exercise to improve air distribution system is expected to improve overall building reliability and enhancing thermal comfort for occupants. The findings contribute to a scalable framework for retrofitting chilled water networks, offering projected annual savings of RM 840,000 and a payback period of 4.5 years.

Keywords: Energy retrofit; Chilled water network; Chiller plant; Energy efficiency; Existing building

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Green Extraction of Semi-Polar Volatile Compounds from Salvia Officinalis Leaves

Soong Ling Hooi[1], Bee Lin Chua[1], Hada Masayu Ismail[2,3]

[1] School of Engineering, Sunway University, Malaysia

[2] School of Engineering, Taylor's University Lakeside Campus, Malaysia

[3] Natural Products Division, Forest Research Institute Malaysia, Malaysia

Corresponding Author: Bee Lin Chua (e-mail: beelinc@sunway.edu.my)

ABSTRACT

Salvia officinalis L. contains valuable volatile bioactive compounds, such as oxygenated terpenoids and hydrocarbon monoterpenes, which are highly sought after for pharmaceutical and nutraceutical applications. However, there is still limited work on using a green biphasic solvent system combined with ultrasound-assisted extraction (UAE) and response surface methodology (RSM) to selectively recover these compounds from *Salvia officinalis* L. Hence, this study developed a green extraction approach integrating polarity-tuned biphasic solvents with UAE. The research involved three stages: (i) preliminary HS-SPME-GC-MS profiling, which identified camphor (30.06%) and α-thujone (28.14%) as major compounds; (ii) screening of suitable biphasic green solvent systems using ethanol (20-70% v/v), with two geraniol-based DES mixtures, one chlorine chloride-mixture and cyclopentyl methyl ether (CPME) in biphasic systems prepared at a 1:1 phase ratio; and (iii) optimisation of the ethanol-CPME biphasic system. Initial solvent screening under UAE was carried out at 32 °C for 16 min with a solid-to-liquid ratio of 1:20. Results indicated that the ethanol–CPME system selectively enriched less polar terpenoids with camphor (9.06×10^6) showing more than three-fold increase in the CPME phase compared with ethanol (2.57×10^6). UAE optimisation of the CPME layer was performed using a 15-run Box-Behnken design (BBD) varying extraction temperature (32, 46, and 60 °C), sonication time (16, 38, and 60 min), and solid-to-liquid ratio (1:20, 1:35, and 1:50). Second-order polynomial models were suitable for eucalyptol and humulene, whereas linear models were selected for camphor and thujones. The fitted models yielded R^2 values of 0.9411 for eucalyptol, 0.8137 for thujones, 0.8078 for camphor, and 0.9438 for humulene. However, the low predicted R^2 for eucalyptol (0.0583) indicated weaker predictive performance for this compound. The solid-to-liquid ratio was identified as the dominant factor influencing the CPME-phase responses. Under the optimized conditions (32 °C, 60 min, and 1:20 ratio), the CPME layer showed strong GC-MS responses for camphor, humulene and thujone, with peak areas of approximately 9.06×10^6, 5.09×10^6 and 1.57×10^6 respectively. Overall, the study demonstrates that ethanol–CPME biphasic UAE is a promising green approach for the selective enrichment of sage terpenoids, with camphor and humulene serving as reliable marker compounds for process optimisation.

Keywords: Salvia officinalis leaves; Volatile compounds; Deep eutectic solvents; Ultrasound-assisted extraction; Response surface methodology

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Hydrothermal operations of palm empty fruit bunch fibers for value added products

Rui Hong Teoh[1], Suchithra Thangalazhy-Gopakumar[1]

[1] Department of Chemical and Environmental Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia, Jalan Broga, 43500, Semenyih, Selangor, Malaysia
Corresponding Author: Suchithra.Thangalazhy@nottingham.edu.my

ABSTRACT

A major byproduct of the palm oil industry is palm empty fruit bunch (EFB) fiber, which can be used as an organic source for energy and chemicals. Wet torrefaction is a thermochemical pretreatment that destroys the cellular matrix of the biomass through depolymerization in hot compressed water. Wet torrefaction can be used to improve the energy properties and homogenization of EFB and improve its fuel characteristics as a result. The wet torrefaction experiments were conducted in a stirred high-pressure reactor autoclave with a volume of 1 liter. Approximately 10g of EFB was weighed and added into the reactor. This was followed by the addition of 150 mL of deionized water. Proximate and ultimate analyses were conducted on the torrefied biomass, along with Fourier Transform Infrared Spectroscopy (FTIR), and Thermogravimetric (TGA) analyses. In second set of studies, Hydrothermal liquefaction (HTL) of EFB was conducted to produce biocrude oil. The temperature for HTL was set as and 275 ^{o}C with the water to biomass ratio as 10:1. The liquid products from HTL were further treated with hydrogen for 30 minutes at 180 ^{o}C. The resultant liquid products were analyzed with Gas Chromatography - Mass Spectrometry (GC-MS). The hydrotreated liquid had high content of phenol which can be extracted as value added chemical.

Keywords: Hydrothermal liquefaction; Wet torrefaction; Hydrolysis, Palm empty fruit bunch fibers; Phenol

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Sustainable Valorisation of *Moringa oleifera* and Palm Kernel Expeller for Poultry Feed: From Bromelain-Assisted Extraction Kinetics to Functional Pellet Formulation

Abbhiramy S. Anandan, Yen Keat Khoo, Shyh Khae Pea, Sze Pheng Ong

Department of Chemical and Environmental Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia, Jalan Broga, 43500 Semenyih, Selangor, Malaysia. *Corresponding Author:* sze-pheng.ong@nottingham.edu.my

ABSTRACT

The poultry industry's heavy reliance on imported protein sources, such as soybean meal, necessitates the development of sustainable, locally sourced alternatives to enhance food security. This study investigates an integrated process for the valorisation of *Moringa oleifera* leaves and palm kernel expeller (PKE) to create a nutrient-enriched poultry feed. The approach involved two main phases: the enzyme-assisted bioactive extraction and the subsequent formulation of functional feed pellets. Initially, bromelain-assisted extraction was employed to recover proteins, antioxidants, and iron from Moringa leaves. Using response surface methodology, the process was analysed to determine the influence of temperature, enzyme concentration, and time, identifying optimal conditions at 40 °C with a 25% weight-by-volume enzyme concentration. Kinetic modelling using the second-order model provided the most accurate description of the extraction dynamics (R^2 > 0.95), revealing a biphasic release pattern. In the second phase, the processed Moringa was incorporated into PKE at varying formulations. The results demonstrated that a 30% weight inclusion of Moringa achieved a significant protein content of 20% (195 mg/g) while substantially enhancing antioxidant capacity. To ensure physical durability, texture analysis was performed, identifying xanthan gum as a superior binder for maintaining pellet structural integrity. This work contributes to chemical engineering by providing a mechanistic framework for enzyme-assisted biorefinery processes and biomass valorisation. By integrating kinetic modelling with product design, the study offers a practical, industrial solution for reducing agricultural waste and improving resource efficiency within the circular economy. This integrated strategy addresses a critical societal need for sustainable animal feed production while advancing the fundamental understanding of enzyme-biomass interactions in food engineering applications.

Keywords: Moringa oleifera; Bromelain; Kinetic modelling: Palm kernel expeller; Poultry feed

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Evaluation of Menthol:Lauric Acid Hydrophobic Deep Eutectic Solvent in The Removal of Malachite Green from Water

Wei Jun Sim[1], Hui San Thiam[1], M. Zulhaziman M. Salleh[3], Yee-Sern Ng[1,2*]

[1] Department of Chemical Engineering, Universiti Tunku Abdul Rahman, Malaysia
[2] Centre for Advanced and Sustainable Materials Research, Universiti Tunku Abdul Rahman, Malaysia
[3] Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia, Malaysia

Corresponding Author: ngys@utar.edu.my

ABSTRACT

Dye-containing wastewater is a significant source of water pollution if discharged without proper treatment. Liquid–liquid extraction (LLE) is one of the wastewater treatment methods that can effectively remove dye from the wastewater. However, this method often utilises organic solvents such as hexane and kerosene, which are volatile and toxic to both humans and environment. Therefore, the search for alternative greener solvents is necessary. Hydrophobic deep eutectic solvents (HDESs) have emerged as promising alternatives due to their favourable characteristics, such as tunable properties and ability to be synthesised from natural compounds. In this study, an HDES based on Menthol:Lauric Acid at molar ratio of 2:1 was investigated as the solvent for the removal of malachite green from water, owing to the widespread use of this dye in the textile industry and its associated environmental concerns. The study was carried out by contacting the HDES with synthetic dye wastewater, which was malachite green aqueous solution, in laboratory-scale experiments. The dye extraction performance of the HDES was evaluated under different parameters, namely pH of malachite green solution (pH 3–9), solution-to-HDES ratio (3–75 mL/g), and initial malachite green concentration in the solution (50–400 ppm). The results demonstrated that the HDES achieved extraction efficiencies exceeding 95% under neutral to alkaline conditions (pH 7–9) and at solution-to-HDES ratios between 3–12 mL/g. In contrast, the extraction performance was less affected by the initial dye concentration within the investigated range. These findings revealed that Menthol:Lauric Acid HDES has strong potential as the alternative solvent in LLE for efficient dye removal from water.

Keywords: Hydrophobic deep eutectic solvent; Malachite green; Liquid-liquid extraction; Water

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CO_2 Capture and Sequestration: Principles and Simulation of a Supersonic Gas Conditioning System

Xavier Henry[1], Abdul Aziz Omar[1]

[1] School of Engineering, Faculty of Engineering and Technology, Sunway University, Malaysia

Corresponding Author: abdulazizo@imail.sunway.edu.my (A. A. Omar)

ABSTRACT

The monetisation of Malaysia's high carbon dioxide (CO_2) natural gas (NG) fields is critical for global energy security, yet conventional offshore separation technologies often remain constrained by the associated footprint and weight limitations. In response, this study evaluates the feasibility of supersonic NG conditioning as a compact, chemical-free and integrated pre-treatment solution for the removal of acid gases (CO_2 and hydrogen sulphide (H_2S)), though significant research gaps remain regarding equipment scalability and transient-flow stability. To address these gaps, dual-simulation approach was employed with Aspen HYSYS utilised for thermodynamic optimisation and Ansys FLUENT for computational fluid dynamics (CFD) analysis. The results demonstrate a robust bulk pre-treatment capability, achieving a minimum removal efficiency of 70% for CO_2 and 85% for H_2S. Steady-state CFD study showed a developed supersonic core with an axis-averaged Mach 1.6 to 1.8 but predicts deep subcooling to about 150 K, implying a potential risk of solid CO_2 formation during practical operation. Next, transient CFD analysis reveals unsteady shock oscillations and pressure pulsations inside the unit, both of which reduce acid gas separation efficiency relative to steady-state predictions and pose challenges for stable operation. Moreover, a half-scale model assessment confirms aerodynamic stability for floating liquified NG (FLNG) applications but highlights a residence time deficit that restricts condensate droplet growth and subsequent separation performance. Despite these limitations, this technology is well-positioned as an energy efficient bulk separator that uses intrinsic pressure energy to significantly lowers downstream processing load. This study progresses the oil and gas upstream sector by providing a potential scalable design framework and the steps required to further refine it while aligning with the National Energy Transition Roadmap (NETR) and Carbon Capture and Sequestration (CCS) initiatives, thus, offering a sustainable path for developing stranded high impurity NG reserves while minimizing the industrial environmental footprint.

Keywords: Supersonic separation; Natural gas conditioning; Carbon capture, Computational fluid dynamics, transient analysis

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Computer-Aided Molecular Design of Renewable and Thermally Stable Hydrocarbon Base Oils: A Quasi-PAO Approach for Sustainable Lubricants

Xiao Syuen Lim, Lik Yin Ng, Nishanth Chemmangattuvalappil*
School of Engineering, Sunway University, Malaysia.

Corresponding Author: nishanthg@sunway.edu.my

ABSTRACT

The transition from petroleum-based lubricants to sustainable alternatives is limited by poor oxidative stability, inadequate low-temperature performance, and limited long-term thermal resistance of existing bio-ester. Conventional improvement strategies using secondary additives or surface-level chemical modifications of vegetable oils often improve only certain properties while leaving the underlying structural weaknesses unresolved. This necessitates the incorporation of thermodynamic stability directly into a Computer-Aided Molecular Design (CAMD) framework for renewable lubricant development. This framework utilizes a flexible building block pool of C8 to C22 fatty acids, simulating vegetable oil feedstock derivatives to perform refunctionalization. Through dehydration, oligomerization, and hydrogenation reaction-consistent pathways, these intermediates are reconstructed into branched saturated hydrocarbon architectures similar to polyalphaolefin-type lubricants. Synthesizability is enforced by restricting designs to chemically feasible and scalable reaction routes. Simultaneous thermodynamic stability criteria are also incorporated into the design algorithm specifying Gibbs free energy requirements to screen synthesis and thermal degradation pathways. The framework systematically evaluates candidate molecules targeting ISO Viscosity Grade (VG) 15 to 46 lubricant applications. Results show that the designed molecules exhibit desired thermodynamic stability, with positive Gibbs free energy values for degradation pathways under operational conditions, confirming resistance toward spontaneous hydrolysis, oxidation and decomposition. Overall, this work demonstrates the potential predictive molecular-level design of sustainable bio-lubricants, strengthening the integration of thermodynamic screening with molecular architecture design.

Keywords: Computer-aided molecular design, Bio-lubricants, Fatty acids, Thermodynamic stability, Gibbs free energy

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Optimising Resource Allocation Trade-offs for an Integrated Decarbonisation Strategy Across the Food-Energy-Water-Waste Nexus

Xin Hui Cheng[1], Jean Pimentel[2], Botond Bertok[2], Bing Shen How[1], Viknesh Andiappan[1,*]

[1] Research Centre for Sustainable Technologies, Faculty of Engineering, Computing and Science, Swinburne University of Technology Sarawak, Malaysia
[2] Department of Systems Science, Széchenyi István University, Egyetem tér 1., H-9026 Győr, Hungary
Corresponding Author: vmurugappan@swinburne.edu.my

ABSTRACT

As the global transition towards low-carbon energy systems accelerates, decarbonisation efforts are constrained by resources such as land, water, and energy, which are typically shared across the food, energy, water, and waste (FEW^2) sectors. However, current sector-specific planning across the FEW^2 sectors is often performed in silos, overlooking the complex interdependencies and potential conflicts in resource use among these sectors. For example, expanding renewable energy such as solar power may induce land competition with the food sector for crop production. Meanwhile, waste can be used for energy generation or converted into fertiliser to support crop production, demonstrating the competing pathways of resource use across food and energy sectors. Moreover, reducing emissions in one sector may increase resource demands and the associated emissions in the others, potentially shifting the emissions to another sector instead of removing them. These challenges highlight the strong interdependencies in resource use across the FEW^2 sectors and the necessities of considering the FEW^2 sectors as an integrated system when designing decarbonisation strategies. Hence, this study develops a strategic resource allocation framework that integrates cross-sectoral decarbonisation planning using P-graph. P-graph is a graph-theoretic optimisation framework that identifies the optimal solution and a ranked set of near-optimal (also known as N-best) solutions. The resulting solutions are subsequently analysed to identify optimal decarbonisation and resource allocation strategies. Applied to a case study in Peninsular Malaysia, key findings include identification of (1) optimal resource allocation, (2) optimal level of decarbonisation in each sector, and (3) strategy that satisfies all sectoral demands while meeting the sector-specific decarbonisation goals. These findings allow decision-makers to systematically compare N-best resource allocation and decarbonisation strategies, supporting the development of an integrated decarbonisation planning with optimal resource allocation across the FEW^2 sectors.

Keywords: Food-energy-water-waste nexus, Decarbonisation, Cross-sectoral resource allocation, P-graph, N-best resource allocations

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Computational Design of Natural Deep Eutectic Solvent (NADES) to Enhance Skin Penetration of Clotrimazole for Fungal Infections

Lai Yong Xuan[1], Azizul Azri Bin Mustaffa[1,2]

[1] Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

[2] Centre of Lipids Engineering and Applied Research (CLEAR), Ibnu-Sina Institute for Scientific and Industrial Research (ISI-SIR), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Corresponding Author: azizulazri@utm.my

ABSTRACT

The high levels of humidity and heat found in Malaysia create optimal conditions for the growth of dermatophytes, making superficial fungal infections a serious problem for dermatologists in that country. While clotrimazole is a standard treatment, its clinical effectiveness is often limited by very low aqueous solubility, which subsequently prevents the drug from penetrating the skin layers effectively. To address this problem, this study developed a computational framework for designing Natural Deep Eutectic Solvents (NADES) as higher-performing carriers. A computer-aided molecular design (CAMD) approach was used to screen 19 hydrogen-bond acceptors and 38 hydrogen-bond donors, yielding a library of 845 potential combinations. To ensure the screening was accurate, evaluation data were integrated from available literature and simulations using the Conductor-like Screening Model for Real Solvents (COSMO-RS), ProTox 3.0, and the Ionic Liquid Toxicity Database (ILToxDB). The filtering stage required a molecular weight (MW) below 500 Da, a half-maximal inhibitory concentration (IC_{50}) above 50 mM, and activity coefficients between 0.1 and 1.0. There were six NADES formulations that fulfilled all filtering criteria out of the 845 candidates that were screened. The best-performing system, a 1:1 molar ratio of betaine hydrochloride and propylene glycol, reached a predicted solubility of 144.92 mg/mL. This result is much higher than the solubility of ethanol, which only reached 64.39 mg/mL. From a practical perspective, a 1% weight per volume formulation using this NADES required only 6.90 g of solvent at an estimated cost of RM 0.70, compared to RM 0.72 and 15.53 g for ethanol. Overall, these results demonstrate that data-driven screening can effectively replace traditional trial-and-error methods in formulation design. This approach provides a resource-efficient way to improve drug delivery and offers a low-cost, scalable solution for the pharmaceutical industry to treat common skin infections.

Keywords: Natural deep eutectic solvents; Clotrimazole; Computer-aided molecular design; Solubility enhancement; Topical drug delivery

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Size and Charge Selective Filtration Performance of a Self-healing Chitosan/Polyacrylamide-Coated Polyethersulfone Membrane

Yung Xin Koh[1], Sheng-Jie You[2,3], Ya-Fen Wang[2,3], Kok Chung Chong[2,4], Yean Ling Pang[1,4], Woon Chan Chong[1,4*]

[1] *Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Sungai Long Campus, Jalan Sungai Long, Cheras 43000 Kajang, Selangor, Malaysia.*
[2] *Department of Environmental Engineering, Chung Yuan Christian University, Taoyuan 320314, Taiwan.*
[3] *Center for Environmental Risk Management, Chung Yuan Christian University, Taoyuan 32023, Taiwan*
[4] *Centre for Advanced and Sustainable Materials Research, Universiti Tunku Abdul Rahman, Sungai Long Campus, Jalan Sungai Long, Cheras 43000 Kajang, Selangor, Malaysia.*

**Corresponding Author: chongwchan@utar.edu.my*

ABSTRACT

The integration of self-healing functionality into membrane filtration systems provides a promising strategy to mitigate structural damage and enhanced membrane lifespan. Hereby, chitosan/polyacrylamide-coated polyethersulfone (CS/PAM-PES) membranes were fabricated to investigate the separation behaviour and self-healing mechanism. The rejection performance towards tartrazine (anionic micromolecule) and bovine serum albumin (BSA, anionic macromolecule) was evaluated under undamaged, damaged and healed states. A size exclusion was identified as the fundamental mechanism in membrane separation process. The separation mechanism of CS/PAM-PES membrane was evaluated based on the separation of molecules with distinct size. The membrane achieved high separation towards BSA molecules (72.24%) compared to tartrazine, primarily due to size exclusion, suggesting that the CS/PAM coating effectively reduced the effective pore size of PES support layer. Upon physical damage, the rejection performance significantly declined, particularly for BSA (30.91%), indicating that the disruption of the selective layer and the formation of defects on the polymer network. After the healing process, the BSA rejection restored to 76.25%, indicating the successful reconnection of polymer network through the dynamic intermolecular hydrogen bonding and re-entanglement of polymer chains. During the healing process, water enhanced polymer mobility, allowing the CS/PAM layer swell and reform dynamic bonding with free active amine and amide groups in CS/PAM layer. In contrast, the rejection of small tartrazine molecules unable to fully restore after healing, implying incomplete recovery of the original pore size distribution. These observations suggest that CS/PAM coating simultaneously enhances the separation efficiency and imparts intrinsic self-healing capability, provides a potential approach for the development of durable and sustainable filtration membranes.

Keywords: Self-healing membrane; Water-responsive; Reversible bonding; Size exclusion

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Influence of Inoculum Source on Biogas Production and Kinetic Behaviour during Anaerobic Digestion of Food Waste

Wai Hong Loh[1], Chong Zhao Jer[1], Yi Jing Chan[1],

[1] Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, Malaysia.

Corresponding Author: Yi-Jing.Chan@nottingham.edu.my

ABSTRACT

Anaerobic digestion provides a sustainable approach for converting food waste into renewable biogas. However, digestion performance is strongly influenced by inoculum characteristics and operating conditions. This study compared the biogas production performance and kinetic behaviour of food waste anaerobic digestion using anaerobic sludge (AS) and cow dung (CD) as inoculum sources. The AS was collected from an anaerobic digester treating palm oil mill effluent at a local palm oil mill. A total of 50 batch experimental sets were evaluated, comprising 25 sets for each inoculum source under different inoculum concentrations and organic loadings. Cumulative biogas production was monitored and further analysed using the Modified Gompertz Model (MGM), Logistic Function Model (LFM), and First Order Model (FOM) to describe the production behaviour of both inocula. The highest cumulative biogas production for both inoculum sources was observed in Set 3, which was operated at an inoculum concentration of 20,000 mg total solids/L and an organic loading of 15 g volatile solids/L. Under these conditions, AS achieved 4650 mL of cumulative biogas with a methane yield of 741 mL CH_4/g VS, whereas CD produced 400 mL of cumulative biogas with a methane yield of 64 mL CH_4/g VS. The kinetic analysis showed that MGM provided the best representation of cumulative biogas production for both inoculum sources. For AS, MGM achieved an R^2 of 0.999 and WAPE of 1.00%, while the corresponding values for CD were 0.995 and 3.21%. The model effectively described the progression of biogas production and provided useful kinetic parameters for comparing digestion behaviour between the two inocula. Overall, the results demonstrate that inoculum source significantly influenced both biogas production performance and kinetic characteristics, with AS showing substantially greater biogas and methane production than CD. The findings also highlight the usefulness of kinetic modelling for interpreting digestion performance and supporting the optimisation of food waste anaerobic digestion. Further investigation of microbial communities, methane composition, and continuous reactor performance is recommended to support future process scale up.

Keywords: Food waste; Anaerobic digestion; Inoculum source; Anaerobic sludge; Cow dung; Biogas production; Methane yield; Kinetic modelling

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Multivariate Statistical Approach for Low-Carbon Strategy Optimization in Palm Oil Mills

Edbert Gervais de Liyis[1], Yi Jing Chan[1], Hon Loong Lam[1]

[1] Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, Malaysia

Corresponding Author: honloong.lam@nottingham.edu.my

ABSTRACT

As palm oil mills produce large amounts of greenhouse gas, the implementation of Low Emission Development Strategies (LEDS) is very important. However, it requires data-driven operation. Currently, existing emission reduction strategies is mainly composed of static simulations or very disunited operation monitoring. This study identifies a gap in the deployment of advanced statistical models and integrate high-volume mill data across multiple operation parameter into a predictive sustainability model

A Multivariate Statistical Process Control (MSPC) framework built on from Partial Least Squares (PLS) regression is proposed. The PLS model processes datasets and extract latent variables, which analyses the covariance between operation input and outputs. The proposed model is used to predict carbon output. the model is then validated against a calibrated SuperPro Designer process simulation. This will bridge the operational gap between static environmental assessments and dynamic process behaviour, providing a quantitative mechanism to monitor and minimize carbon emissions during continuous mill operations.

Keywords: Multivariate statistical process control; Partial least squares; Low emission development strategies; Palm oil mill effluent; Carbon footprint optimization

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Comparative Study of Extraction Methods and Phytochemical Characterization of Senna Alata Essential Oil

Nabihah Abdullah[1], Fatin Nur Aisyah[1], Abdul Hadi Mat Hassan[1]

[1] Faculty of Engineering Technology (Chemical), University College TATI,Kemaman, Malaysia
Corresponding Author: nabihah@uctati.edu.my

ABSTRACT

Senna alata (L.) Roxb. is a medicinal plant widely utilized in traditional medicine because of its antifungal, antimicrobial, antioxidant, and anti-inflammatory properties. The present study investigated the effects of different extraction techniques and solvents on the extraction yield, phytochemical composition, and thermal properties of *Senna alata* essential oil. Soxhlet extraction and maceration were performed using ethanol and n-hexane, while cold and heat infusion methods utilized virgin coconut oil as the carrier oil. The extracted oils were characterized using Gas Chromatography-Mass Spectrometry (GC-MS), Fourier Transform Infrared Spectroscopy (FTIR), and Thermogravimetric Analysis (TGA). Maceration with hexane produced the highest oil yield (28.5%), followed by maceration with ethanol (17.5%), whereas Soxhlet extraction produced lower yields. GC-MS analysis identified major compounds including phytol, vitamin E, 9,12,15-octadecatrienoic acid, nonacosane and palmitic acid. FTIR spectra confirmed the presence of hydroxyl, carbonyl, and aromatic functional groups associated with phenolics, flavonoids, and fatty acids. TGA analysis demonstrated differences in thermal stability among the extracts depending on solvent polarity and extraction method. The findings suggest that extraction conditions significantly influence the recovery of bioactive compounds from *Senna alata* essential oi and provide useful information for the development of pharmaceutical and nutraceutical applications.

Keywords: Senna alata; Extraction; Essential oil; Natural product; Functional groups

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Investigating the Effects of Ultrasound Stimulation to Optimise Microalgae Growth and Biomass Composition for Biofuels

ZhiWei Cheah[1], Yong Kuen Ho[1], Hwai Chyuan Ong[2], Bey Hing Goh[3], Siah Ying Tang[1]

[1] Department of Chemical Engineering, School of Engineering, Monash University Malaysia
[2] School of Engineering, Faculty of Engineering and Technology, Sunway University
[3] Sunway Biofunctional Molecules Discovery Centre, Sir Jeffrey Cheah Sunway Medical School, Faculty of Medical and Life Sciences, Sunway University

Corresponding Author: patrick.tang@monash.edu

ABSTRACT

Current industrialisation efforts in microalgae cultivation for biofuel production have fallen short, facing significant challenges such as unpredictable biomass yields, fluctuations in biomass composition, and susceptibility to external contamination. These issues largely stem from a lack of control over the cultivation microenvironment in open systems, where it is greatly affected by the surrounding environment, and in turn affects cultivation outcomes. This study aims to address these limitations by having developed a lab-scale closed cultivation system that can control and stabilise the microenvironment, and to enhance biomass yields and composition with the aid of ultrasound stimulation. To achieve this, the study employs a systematic approach involving parametric studies to optimise growth and specific biochemical components within the biomass, extrapolating from existing studies on microalgae within the same genus for a foundational understanding of the microalgae growth behaviour. A key element of this study involves the coupling of an optimised cultivation environment with ultrasound stimulation at specific points in the cultivation cycle as a pretreatment to enhance biomass growth and lipid accumulation. Preliminary studies subjecting batch cultures to 5 minutes of ultrasound pretreatment during the lag phase of the cultivation cycle showed enhancement in lipid accumulation relative to control batch cultures. While still requiring further optimisation, the results show potential in overcoming major hurdles in the commercialisation of microalgae for biofuels by providing a more predictable and high-yielding cultivation method. Furthermore, this research explores the fundamental chemical engineering understanding of how controlling the environment of a process can affect the final product, and how it can be leveraged to optimise bioprocesses for sustainable energy applications.

Keywords: Microalgae cultivation; Photobioreactor systems; Ultrasound stimulation; Lipid accumulation; Biofuel feedstocks

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Investment and Operational Optimisation of a Dual Carbon Capture with Bioenergy System

Norhuda Abdul Manaf[1,3*], Sharmila Loganathan[1], Muhammad Fitri Shahrim[1,3] and Nilay Shah[2]

[1] Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
[2] Department of Chemical Engineering, Imperial College London, SW7 2AZ, United Kingdom
[3] Universiti Kuala Lumpur Malaysia Italy Design Institute (MIDI), Kuala Lumpur, Malaysia

Corresponding Author: norhuda.kl@utm.my

ABSTRACT

The integration of amine-based absorption carbon capture (CC) and direct air capture (DAC) with bioenergy (BG_{CC}^{DAC}) system features a promising technological pathway for mitigating the adverse effect of climate change while simultaneously enabling the production of valuable products, such as hydrogen. This work aims to perform a preliminary investment analysis of the BG_{CC}^{DAC} plant by identifying optimal operating condition and profit generation, using a simplified Gaussian process regression-based surrogate model coupled with a genetic algorithm optimization framework. Under the profit-maximization framework, the optimal solution allocates a 73% CO_2 capture rate to the DAC unit and 15% to the CC unit, corresponding to specific energy penalties of 4.58 MJ/kg CO_2 and 7.66 MJ/kg CO, respectively. The BG_{CC}^{DAC} plant manages to produce high purity of H_2, reaching a maximum of 99% alongside a plant profit of £ 2.6 million/year.

Keywords: Bioenergy; Carbon capture; Direct air capture; Gaussian process regression

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Graphical Screening of Industrial Decarbonization Options

Raymond R. Tan[1], Maria Victoria Migo-Sumagang[2], Kathleen B. Aviso[1], and Dominic C.Y. Foo[3]

[1] Department of Chemical Engineering, De La Salle University, 2401 Taft Avenue, 0922 Manila, Philippines
[2] Department of Chemical Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Los Baños, Laguna, 4031, Philippines
[3] Department Chemical and Environmental Engineering/Centre of Excellence for Green Technologies, University of Nottingham Malaysia, Broga Road, 43500 Semenyih, Selangor, Malaysia

Corresponding Author: dominic.foo@nottingham.edu.my

ABSTRACT

There is growing impetus for corporations to decarbonize in response to global and national net-zero ambitions. Engineers now face the common challenge of screening options to cut corporate greenhouse gas emissions. The marginal abatement cost curve (MACC) is a simple and popular tool for developing decarbonization portfolios, as it rapidly identifies options that cost less than what a company is willing to pay for each unit of emissions mitigation. However, the average mitigation cost given by the combination of all options identified in this manner will generally be less than the company's threshold cost. We present in this work an alternative graphical technique referred to as the average abatement cost curve (AACC), which is based on composite curves used in process integration. Unlike the MACC, the AACC identifies a decarbonization portfolio whose average mitigation cost aligns with the company's willingness to pay threshold. We illustrate this technique using an alumina plant case study.

Keywords: Process integration; Targeting; Graphical method; Mitigation cost; Decarbonization

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Superstructure-Based Mathematical Modelling for Design and Optimisation of Palm Oil Refinery Effluent Wastewater Treatment Plants

Ryan Soh Zhe Hse[1], Wan Yoke Kin[1]*

[1] Department of Chemical and Environmental Engineering, University of Nottingham Malaysia

Corresponding Author: YokeKin.Wan@nottingham.edu.my

ABSTRACT

Treatment plants for palm oil refinery effluent (PORE), an oily medium-strength wastewater product of palm oil refineries, require sequential and optimised design methods to handle high loads of chemical oxygen demand (COD), total suspended solids (TSS) and fats, oils, and grease (FOG). Treated PORE must comply with environmental quality regulations, and ideally, be clean enough to be reused in the refinery itself to reduce freshwater usage and promote circular economy concepts. This study aims to address this need by building a mathematical model to identify the optimal process pathway, or combination of wastewater treatment unit operations, to meet discharge or reuse specifications while minimising decision objectives such as cost, carbon emissions and land footprint. By describing and mapping together all commercially available oil removal, primary, secondary and tertiary treatment options as mathematical equations while considering contaminant removal efficiencies, superstructure-based mathematical modelling (SBMM) allows plant designers to make informed decisions on process pathways that produce treated wastewater that complies with regional environmental discharge standards or plant reuse specifications, with minimum construction and operational expenses, emissions and equipment sizes. SBMM of PORE treatment plants was conducted in LINGO 21.0, which includes volumetric and mass balance equations to model wastewater treatment unit operations, with results on optimised pathways that meet environmental discharge or water reuse standards, and a user-specified decision objective to minimise. The model is designed to be robust and responsive to user input on inlet wastewater specifications, discharge specifications, contaminant removal efficiencies, sludge yield characteristics, cost parameters, emission factors and equipment design parameters. The produced model is therefore widely extendable to different wastewater treatment specifications, providing a foundation for systematic wastewater treatment process design and optimisation at the planning stage.

Keywords: Mathematical modelling; Palm oil refinery effluent (PORE); Wastewater treatment; Cost optimisation; Circular economy

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Liquid Biphasic Flotation as a Novel Strategy for Efficient Extraction of Betalains from Beetroot

Abdirahman Yasin Ibrahim[1], Revathy Sankaran[2*]

[1] Department of Chemical & Petroleum Engineering, Faculty of Engineering, Technology and Built Environment, UCSI University, 56000, Malaysia.

[2] Faculty of Medicine & Health Sciences, UCSI University, 56000, Malaysia., UCSI University, 56000, Malaysia.

Corresponding Author: revathysankaran@ymail.com

ABSTRACT

Betalains are water-soluble, nitrogenous pigments present in plants belonging to the Caryophyllales order, recognized for their striking red-to-yellow hues and notable bioactive characteristics. Beetroot (Beta vulgaris), a widely consumed and traditional vegetable in many regions, including Malaysia, represents one of the most abundant and commercially important sources of these natural pigments. Owing to their strong antioxidant activity, betalains are gaining increasing attention as natural food colorants and nutraceutical components. Nevertheless, traditional extraction techniques often face limitations such as low recovery, presence of impurities, and limited scalability, highlighting the need for more efficient separation strategies. This study explores liquid biphasic flotation (LBF) as an innovative and economical method for the efficient extraction of betalains from beetroot. Key process variables, including solvent and salt selection as well as their respective concentrations, were systematically optimized to enhance extraction yield and maintain pigment stability. Offering benefits such as improved purity, shorter processing times, and potential for industrial-scale application, the LBF-based method presents a sustainable alternative for betalain production. This approach holds promise for advancing applications in the food, pharmaceutical, and cosmetic industries, and may contribute to setting new benchmarks in the downstream processing of plant-derived bioactive compounds.

Keywords: Betalains; Beetroot; Extraction; Antioxidant; Biphasic floatation

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Elucidating the Effects of Organic Matter Chemical Traits on Microbial Priming for Sustainable Soil Management

Jin Teoh[1], Khugann Kumar[1], Ti Sheng Tan[1], Zee Wei Lai[2], Yin Hui Chow[1,4], Yong Kuen Ho[3], Firnaaz Ahamed[1,4,5,*]

[1] School of Engineering, Faculty of Innovation & Technology, Taylor's University, Malaysia
[2] School of Biosciences, Faculty of Health & Medical Sciences, Taylor's University, Malaysia
[3] Department of Chemical Engineering, School of Engineering, Monash University Malaysia, Malaysia
[4] Food Security & Nutrition Impact Lab, Taylor's University, Malaysia
[5] Centre for Sustainable Societies, Taylor's University, Malaysia

Corresponding Author: Firnaaz.Ahamed@taylors.edu.my

ABSTRACT

Microbial degradation of complex organic matter (OM) in soil mediates the exchange of nutrients and energy between microbiome, vegetation, and the surrounding environment. The degradation rate of complex OM can be primed by minor additions of labile (readily bioavailable) OM, prompting accelerated or suppressed degradation rates. Priming can be leveraged to enhance crop productivity, soil health and promote carbon sequestration. However, the fundamental mechanisms of priming remain elusive, hindering its effective application. This research aims to test that microbial priming is driven by the degradation dynamics of complex substrates and influenced by chemical properties of OM including degree of polymerization of complex OM, C/N ratio of labile OM, and relative amounts of labile and complex OM. The soil microbiome was isolated and cultured in minimal media with model polymers simulating complex and labile OM. α-cellulose and microcrystalline cellulose were used to examine the effects of polymerization degree, while glucose, proline, and arginine were used to assess the influence of labile OM C/N ratio. Priming was quantified based on microbial biomass growth (optical density at 600 nm) and residual cellulose concentrations determined using a Congo Red assay. Microbial priming was evident when comparing control samples containing only complex substrates with those supplemented with labile substrates, demonstrated by a significant increase in biomass growth and decrease in residual cellulose. The relative proportions of complex and labile substrates, as well as the C/N ratio of the labile OM, significantly influenced the magnitude of the priming effect. Our findings confirm that degradation dynamics of complex substrates are key in triggering microbial priming, as priming behaviour was replicated under soil-free laboratory conditions using model cellulose polymers and simple organic compounds as complex and labile substrates. Overall, this study demonstrates that microbial degradation dynamics can be strategically manipulated using chemical traits of OM for practical applications.

Keywords: Priming effect; Soil microbiome; Model cellulose polymers; Simple organic compounds; Microbial degradation dynamics

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Operational Strategies and Kinetic Tuning of Ternary Alkali Nitrate-Promoted MgO Sorbents for Low-Concentration CO_2 Capture

Chai Kian Hoong[1], Joyce Tiong[2], Yap Yeow Hong[1]

[1] Department of Chemical Engineering, Universiti Tunku Abdul Rahman, Malaysia

[2] Department of Chemical and Environmental Engineering, University of Nottingham Malaysia Campus, Malaysia

Corresponding Author: yapyh@utar.edu.my

ABSTRACT

Developing efficient intermediate-temperature solid sorbents for post-combustion carbon capture requires addressing both material-level kinetic bottlenecks and reactor-level operating parameters. Molten ternary alkali nitrate-promoted magnesium oxide (MgO) sorbents offer exceptional theoretical capacity for low-concentration CO_2 streams (15%), but practical deployment is severely hindered by prolonged induction periods and sluggish sorption kinetics. This study establishes a unified engineering framework that evaluates operational process control alongside material pre-activation to maximize capture performance without sacrificing throughput. Applying a mild thermal pre-activation step (240°C for 0.5 h) successfully bypasses the $MgCO_3$ pre-nucleation barrier, accelerating the molten-salt dissolution-precipitation pathway and dramatically reducing peak sorption time from 74.2 min to 8.1 min. When this kinetic enhancement is paired with optimized space velocity management (WHSV = 1.7 mL/g·min) at 280°C, the system achieves sustained CO2 removal efficiencies exceeding 81%. Furthermore, complete sorbent regeneration is achieved at temperatures above 320–340°C, demonstrating stable multi-cycle durability across 10 continuous absorption-desorption loops. By integrating intrinsic kinetic tuning with fluid-dynamic process parameters, this work outlines actionable operational windows and system-level design guidelines for scaling nitrate-promoted MgO sorbents in real-world post-combustion flue gas capture applications.

Keywords: MgO sorbent; Ternary alkali metal nitrates mixture; Intermediate temperature CO_2 capture; Dilute CO_2 capture

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Phosphorus Adsorption using Lignin-derived Activated Carbon via Calcium Hydroxide Activation for Domestic Wastewater Treatment

Nurain Azman[1], Nur Hafizah Ab Hamid

[1] Department of Chemical Engineering, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Malaysia
[2] Universiti Teknologi Malaysia, Malaysia

Corresponding Author: nurhafizah.abhamid@utm.my

ABSTRACT

Phosphorus (P) is an essential nutrient in domestic wastewater which primarily comes from food residues, cleaning products and human waste. However, environmental issues such as eutrophication when discharge excessively into natural water bodies source. Nowadays, phosphorus is still being removed from wastewater through biological treatments or precipitation where these methods resulted in stringent operation conditions and only applicable for high phosphate concentration in wastewater. Since domestic wastewater carrying low concentration of phosphate, adsorption presents itself as a valuable alternative due to its low initial cost production and generates low amount of sludge. Adsorption process using lignocellulosic biomass-derived activated carbon is gaining attractions mainly due to its high surface area, pore size distribution and presence of functional groups on adsorbent surface. While lignin can be used as feedstocks, utilization of lignin-based activated carbon is still limited and is primarily burned for power generation. Lignin has potential to be the precursor due to its carbon-rich chemical structures and abundance especially in pulp and paper industry. Thus, this study synthesis the activated carbon from lignin of lignocellulosic biomass for phosphorus removal via chemical activation using calcium hydroxide. Subsequently, the activated carbon produced is subjected to characterization using Fourier Transform Infrared (FTIR) analysis. Batch adsorption test for phosphorus is conducted by varying contact time and initial concentrations where the highest adsorption capacity is 38.88 mg P/g. Adsorption isotherms and kinetics mechanisms of activated carbon are analyzed experimentally by applying Langmuir, Freundlich, Pseudo-order reactions and Intraparticle diffusion models. The lignin-derived activated carbon showed promising result as an alternative to be adsorbent for domestic wastewater treatment for phosphorus removal.

Keywords: Adsorption; Phosphate removal; Activated carbon; Chemical activation; Lignin

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Sustainable Extraction of Nanocrystalline Cellulose through Box–Behnken Optimized Choline Chloride–Oxalic Acid Deep Eutectic Solvent

Menaga Thmil Selvan[1], Akmal Hadi bin Ma'Radzi[1,2], Lee Boon Beng[1,2], Muhammad Syarhabil Ahmad[1,2], Siti Amalina Enche Ab Rahim[3], Ku Azizah Ku Daud[4], Mohd Faizun Zainol Abidin[4], Sohaizam Ismail[4], Mohd Hazir Johar[4], Nurul Izwani Abdul Hamid[4], Yusrizal Yusof[4]

[1] Faculty of Chemical Engineering & Technology, Universiti Malaysia Perlis (UniMAP), Malaysia

[2] Centre of Excellence for Biomass Utilization, Universiti Malaysia Perlis (UniMAP), Malaysia

[3] Microwave Research Institute, Universiti Teknologi MARA, Shah Alam, Selangor

[4] Jabatan Kastam Diraja Malaysia, Kompleks Kastam Negeri Perlis, Malaysia

Corresponding Author: akmalhadi@unimap.edu.my

ABSTRACT

Nanocrystalline cellulose (NCC) is an engineering material that has been widely utilized in various applications. Cigarette filters from seized cigarettes supplied by the Royal Malaysian Customs Department were used in this research to obtain NCC. Deep eutectic solvents (DESs) are a greener alternative in nanocellulose extraction over traditional acid hydrolysis. However, a structured statistical analysis of DES process parameters in NCC extraction from cigarette filters has been overlooked. In this study, green extraction of NCC using a choline chloride oxalic acid DES was optimized by a Box–Behnken design, with DES molar ratio (1–3), temperature (60–120 °C), and time (4–8 h) as the variables. The maximum NCC yield of 68% was obtained by NCC120 (2:2, 120 °C, and 8 hours), and the yield of NCC varied due to the DES acidity, thermal exposure, and residence time. The NCC structural integrity confirmed that the DES system does not alter the cellulose structure. This research has optimized the DES treatment parameters, facilitating a sustainable approach to extract NCC from cigarette filters.

Keywords: Optimization; Nanocrystalline cellulose; Deep eutectic solvent; Cigarette filters; Box-Behnken design

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Evaluation of Household Food Waste Co-composting with Biochar

Jevita Khoo Suk Kim[1], Ng Chin Ting[1], Lau Phei Li[1]

[1] Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, Malaysia.

Corresponding Author: Phei-Li.Lau@nottingham.edu.my

ABSTRACT

The rapid accumulation of household food waste poses a significant environmental challenge, requiring efficient decentralised processing methods to reduce landfill reliance. This study aims to evaluate the co-composting of diverse household food waste, including banana peels, orange peels, pak choy and watermelon rinds, through the integration of biochar to enhance degradation and nutrient stability. The overall approach followed a structured three-stage experimental design: (1) initial physical characterisation, (2) composting via Bokashi anaerobic fermentation with biochar integration, and (3) plant-growth studies. Analysis was performed through systematic physicochemical chatacterisations of moisture, temperature, and pH, supplemented by 21-day plant growth trials using red spinach. Fourier-transform infrared spectroscopy (FTIR) and field emission scanning electron microscopy (FESEM) were employed to analyse functional group transformations and surface morphology. Results showed that the orange and banana peels (OB) mixture reached a consistent mass in 13 hours, whereas the pak choy and watermelon (PCW) rind mixture required 19 hours. While OB achieved significant moisture reduction, PCW exhibited a 1.2% moisture increase post-composting due to its cellular structure. During bokashi fermentation, pH levels dropped to an acidic range of 3.8 to 4.5, which was successfully neutralised to approximately 6.8 upon biochar and soil integration. Growth trials demonstrated that the biochar-compost significantly enhanced plant development in potting mix, reaching a peak height of 28.5 cm compared to 19.5 cm in control groups. FESEM imaging validated that biochar provided a porous scaffold that prevented waste compaction and improved moisture retention. This research advances environmental sustainability by providing clear data for better composting system design, offering further potentials of scaling up. It demonstrates a viable approach to reduce urban waste while improving soil health for agriculture, which addresses the critical need for circular waste management systems.

Keywords: Food waste management; Bokashi fermentation; Biochar, Co-composting; Soil amendment

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Regeneration and Reuse of Activated Carbon for Dye Adsorption under Ambient Conditions Using Dilute Chemical Solutions

Muhammad Alif Basyar Rosli[1], *Anis Suhaila Shuib[2], Suriati Sufian[2]

[1] Production Department, PETRONAS Chemicals Ethylene Sdn. Bhd., Kerteh, Terengganu, Malaysia

[2] Department of Chemical Engineering, Universiti Teknologi PETRONAS, Perak, Malaysia

**Corresponding Author: anis.shuib@utp.edu.my*

ABSTRACT

This study investigated the regeneration and reuse of methylene blue-loaded activated carbon using 0.1 M hydrochloric acid (HCl) and sodium hydroxide (NaOH) under ambient conditions. Batch adsorption experiments were conducted at initial methylene blue concentrations of 10–100 mg/L, followed by four regeneration cycles at 27 ± 2°C. Methylene blue removal ranged from 34.89% to 87.29%. The Freundlich isotherm model provided the best fit to the adsorption data, indicating adsorption on a heterogeneous surface. The regenerated activated carbon retained its adsorption capability over four cycles, with HCl-regenerated activated carbon consistently exhibiting higher regeneration efficiencies than NaOH-regenerated activated carbon. The results demonstrate that dilute chemical regeneration under ambient conditions is a practical approach for extending the service life of activated carbon and supporting sustainable wastewater treatment. The study addresses sustainable chemical engineering solutions for global challenges in water treatment and resource management, supporting Sustainable Development Goal (SDG) 6 - Clean Water and Sanitation, and SDG 12 - Responsible Consumption and Production.

Keywords: Activated carbon; Regeneration; Methylene blue; Chemical treatment; Adsorption

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Production of Cookies from Composite Wheat and Plantain Flour using Peanut Paste as a Fat Replacer

Sunday Boladale Alabi[1], Chiedozie Victor Ifezuligbo[2]

[1] Department of Chemical Engineering, University of Uyo, Nigeria
[2] Department of Chemical Engineering, University of Uyo, Nigeria

Corresponding Author: sundayalabi@uniuyo.edu.ng

ABSTRACT

Cookies are consumed extensively all over the world as a snack food. The commercially available cookies are typically produced from wheat flour, margarine and other ingredients. Unfortunately, margarine has high contents of saturated fats which when consumed in large quantities for a long period of time may lead to increased cholesterol levels in the body and poses risk of heart disease. In Nigeria, 97% of wheat used for producing wheat-based products including cookies, are imported. This results in a huge capital flight. Consequently, to address the economic disadvantage of wheat importation into the country and the use of margarine in the cookies production, this study investigated the production of cookies using composite wheat and plantain flours supplemented with peanut paste as a fat replacer. Cookies were produced from different ratios of wheat flour and plantain flours. The results showed that the new cookies produced from composite wheat and plantain flour in 1:1 have higher protein contents of 12%, lower fat contents of 14.3% and improved texture profile when compared to the commercial cookies which have 8% protein contents and fat contents of 25%. It can therefore be concluded that cookies produced from composite imported wheat and locally available plantain flours using peanut paste is nutritionally better than the typical commercially available cookies. Moreover, the new cookies production has the potential to cut down the cost of wheat importation.

Keywords: Cookies; Composite flour; Wheat; Peanut paste; Fat replacer

POSTER PRESENTATIONS

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Managing Conflicting Goals between Carbon Trading Stakeholders using Quality-Driven Carbon Credit Pinch Analysis

Delia Yi Shi Cheng[1], Yick Eu Chew[1], Adeline Shu Ting Tan[1], Viknesh Andiappan[1,*], Bing Shen How[1]

[1] Research Centre for Sustainable Technologies, Faculty of Engineering, Computing and Science, Swinburne University of Technology Sarawak, Jalan Simpang Tiga, 93350, Kuching, Sarawak, Malaysia.

vmurugappan@swinburne.edu.my

ABSTRACT

Limiting global warming to well below 2°C remains challenging for hard-to-abate industries, whose residual emissions cannot be eliminated solely through direct reductions. Carbon credit trading, therefore, serves as an economic instrument to offset these emissions while supporting the development of carbon dioxide removal (CDR). Recent discussions at the Conference of the Parties (COP30) have shifted attention from credit quantity to quality, particularly durability. This emphasis further highlights conflicting interests among carbon-trading stakeholders, where industry seeks to minimize costs, while governments prioritize maximum effective CDR. To address this conflict, a novel quality-driven carbon credit pinch analysis method was developed by incorporating Climate Repair Value (CRV) to account for credit quality. A Malaysian case study was conducted to demonstrate its applicability by considering five CDR technologies against the emissions demand of seven hard-to-abate industries. Two baseline scenarios were examined: (i) cost-driven pinch analysis representing industry preference and (ii) quality-driven pinch analysis that incorporates CRV representing policymaker preference. Subsequently, a trade-off scenario was determined using the max-min aggregation method to determine a compromise credit purchasing scheme without overprioritizing either stakeholder. All scenarios were evaluated through two credit pricing conditions (i.e., low-end and high-end). Under low-end selling price conditions, closing 42% of the budget gap between the two baseline scenarios increased the achievable effective carbon removal by 58.28% based on the cost-driven baseline. To meet the government's goal under the quality-driven scenario, an additional 1.47 billion $/yr is needed. In contrast, under high-end selling price conditions, closing 49.4% of the budget gap between the baseline scenarios increased the achievable effective CDR by 50.62% relative to the cost-driven baseline. However, an additional 4.02 billion $/yr is required to meet the same target. These additional funds would require government support through incentives, subsidies, or tax measures. The proposed methodology therefore supports decision-making by industry and policymakers in managing conflicting stakeholder goals.

Keywords: Net-zero transition; Process integration; Negative emission technologies; Graphical approach; Max-min aggregation

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Multi-Period Demand-Side Planning of Quality-Constrained Carbon Credit Procurement Using Pinch Analysis

Rachel Xi En Yii[1], Adeline Shu Ting Tan[1], Yick Eu Chew[1], Bing Shen How[1], Viknesh Andiappan[1]

[1] Research Centre for Sustainable Technologies, Faculty of Engineering, Computing and Science, Swinburne University of Technology Sarawak, Jalan Simpang Tiga, 93350, Kuching, Sarawak, Malaysia.

Corresponding Author: BSHow@swinburne.edu.my

ABSTRACT

Carbon credit trading is an important economic instrument that supports industries, particularly hard-to-abate sectors, in meeting increasingly stringent emissions targets. Recently, greater attention has been given to ensuring the quality of carbon credits (eg., expressed in terms of durability), as credits with lower permanence may provide less effective long-term emissions removal. However, planning quality-constrained carbon credit procurement across multiple compliance periods remains challenging due to variations in credit availability, budget constraints and credit durability. This study proposes a systematic framework for multi-period carbon credit planning using a quality-constrained carbon credit pinch analysis integrated with climate repair value (CRV), a metric that quantifies the quality of carbon credits based on durability. The approach applies composite curve analysis to evaluate the balance between carbon credit supply and demand over a defined planning horizon. A baseline pinch analysis is first performed to determine deficits between effective carbon credit supply and sectoral demand under CRV correction. The analysis is then extended to a multi-period pinch framework to assess how temporal constraints influence carbon credit procurement requirements. Demand-side planning (DSP) strategies are subsequently applied to reduce external credit requirements and credit waste through redistribution of carbon credit demand across the planning horizon. In an alternative scenario, the time value of carbon is incorporated to account for the environmental impact of delayed emissions reduction. An inflation factor is applied to represent the additional carbon credits procurement penalty arising from the time value of carbon. The results show that DSP significantly reduces external carbon credit requirements by approximately 64%. However, when the time value of carbon is considered, the DSP can only reduce the external carbon credit requirements by approximately 29%. These findings highlight that ignoring time value of carbon can underestimate the true carbon credit requirement. The proposed methodology provides a decision-support tool for long-term carbon credit procurement planning.

Keywords: Carbon credit planning; Pinch analysis; Demand-side planning; Climate repair value; Multi-period optimization

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Process Simulation and Validation of a 750 MW Malaysian CCGT Power Plant for Flexible Operation Under Energy Transition Challenges

Siti Sorfina Johari[1], Rohani Mohd Zin[2], Tengku Amran Tengku Mohd[2]

[1] Energy Generation, TNB Research Sdn Bhd, Malaysia

[2] Faculty of Chemical Engineering, UiTM Shah Alam, Malaysia

Corresponding Author: sorfina.johari@tnb.com.my | rohanimz@uitm.edu.my

ABSTRACT

Malaysia's commitment toward net zero emissions by 2050 requires existing baseload power plants to operate with greater reliability, flexibility, and readiness in response to evolving grid and operational requirements. Combined cycle gas turbine (CCGT) power plants remain important for providing stable electricity generation due to their high efficiency, fast response capability, and suitability for supporting variable renewable energy integration. However, changes in operating demand and process conditions may affect overall plant performance, making validated simulation tools valuable for operator decision-making and troubleshooting. This study aims to model and validate a 750 MW Malaysian baseload CCGT power plant using Aspen HYSYS V14 to provide a reliable process simulation platform for performance assessment before actual plant adjustments are implemented. The model was developed using the Soave–Redlich–Kwong (SRK) fluid package based on the main CCGT configuration including the gas turbine (GT), heat recovery steam generator (HRSG), steam turbine (ST), condenser, and associated power generation systems. Actual plant operating data, including power demand and key process parameters, were used as input and reference values for model validation. The simulated plant performance was compared against actual plant data to evaluate model accuracy. Results show that the developed model successfully represents the Malaysian baseload CCGT power plant, with an overall power output deviation of only 2.45% from the actual plant data. In addition, the percentage differences obtained for the GT, HRSG, ST, and condenser sections were in range of 2.00%-8.03%, indicating good agreement between the simulation and actual operating performance across major plant systems. The validated simulation model is suitable for preliminary performance monitoring, operational evaluation, and troubleshooting studies. This work contributes toward practical power plant digitalization and supports more informed operation of existing thermal assets during Malaysia's transition toward net zero emissions by 2050.

Keywords: Combine cycle gas turbine; Aspen HYSYS; Power plant simulation; Model validation; Net zero 2050

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Design of Optimal Lubricants through Computer-Aided Approach

Xian Zhuang Chong[1], Nishanth Gopalakrishnan Chemmangattuvalappil[1], Lik Yin Ng[1]

[1] Faculty of Engineering and Technology, Sunway University, Malaysia

Corresponding Author: likyinn@sunway.edu.my

ABSTRACT

The depletion of fossil fuel reserves and increasing environmental concerns have necessitated the transition towards sustainable, biodegradable lubrication alternatives. However, natural vegetable oils often exhibit physicochemical limitations, such as poor low-temperature fluidity and oxidative instability, which restrict their industrial application. This study aims to address these limitations by developing an integrated Computer-Aided Molecular Design framework to identify optimal biolubricant from vegetable oil feedstocks. The framework utilizes Rough Set Machine Learning to analyze 31 vegetable oils. The generated predictive rules were used to identify critical property targets, specifically dynamic viscosity and pour point. Five molecules were generated and verified using Kappa indices (k_1, k_2) to quantify the relationship between molecular architecture and performance. The results demonstrated that all candidates met the dynamic viscosity target, but their thermal stability varied based on structural topology. Solution 1 was identified as the optimal design, achieving an exceptional Viscosity Index of 501.83. This significantly surpasses conventional mineral oils, due to its compact topological profile (k_2 = 37.8) and a balanced degree of unsaturation, which maintains hydrodynamic stability without excessive polarity observed in lower-performing candidate. The proposed framework effectively translates target physicochemical properties into feasible molecular designs, offering a promising pathway for developing high-performance, sustainable biolubricants.

Keywords: Biolubricant oil; Computer-aided molecular design (CAMD); Rough set machine learning (ROSE 2); Kappa indices; Pour point; Viscosity index

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Prediction and Optimisation of Food Waste Anaerobic Digestion Using Artificial Neural Network and Genetic Algorithm

Chan Yi Jing
Department of Chemical Engineering, University of Nottingham, Malaysia
Corresponding Author: Yi-Jing.Chan@nottingham.edu.my

ABSTRACT

Anaerobic digestion is a sustainable approach to convert food waste into renewable energy. However, process performance is affected by nonlinear interactions between sludge inoculum concentration and organic loading. This study developed an artificial neural network model to predict biogas production and methane yield from food waste anaerobic digestion. Anaerobic sludge and cow dung were modelled separately to compare their process behaviour. The model showed high prediction accuracy for biogas production, with R^2 values of 0.9854 for anaerobic sludge and 0.9196 for cow dung. Methane yield prediction was more complex, with R^2 values of 0.5054 and 0.8951 for anaerobic sludge and cow dung, respectively. Sensitivity analysis showed that sludge inoculum concentration (SIC) strongly influenced methane yield, while organic loading (OL) mainly affected biogas production. A Genetic Algorithm (GA) was integrated with the ANN to optimise operating conditions. For anaerobic sludge, optimal conditions were identified at SIC between 19,500 and 19,800 mg/L and OLR between 14 and 15 g VS/L, resulting in biogas production up to 4595.79 mL and methane yield up to 738.68 mL CH_4/g VS. In contrast, the cow dung system exhibited a clear trade-off, where low OL (3 g VS/L) maximised methane yield (109.40 mL CH_4/g VS), while high OLR (15 g VS/L) enhanced biogas production up to 317.82 mL with lower methane yield. These findings demonstrate that ANN combined with GA optimisation provides an effective decision-support framework for improving AD performance. The findings also highlight the importance of inoculum selection in improving methane recovery and process performance.

Keywords: Anaerobic digestion; Artificial neural network; Genetic algorithm; Food waste; Biogas; Sensitivity analysis

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Liquid-Liquid Extraction for the Separation of Binary Mixture Composed of Acetonitrile and Benzene with Emim-Based Ionic Liquids

Wee Jia Jun [1], Er Zhi En [1], Ong Jin Liang [1], and Ianatul Khoiroh [1]

[1] Department of Chemical & Environmental Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia

Corresponding Author: ianatul.khoiroh@nottingham.edu.my

ABSTRACT

The performance of three ionic liquids, namely 1-ethyl-3-methyl imidazolium trifluoromethanesulfonate or [EMIM][Tf], 1-ethyl-3-methyl imidazolium tetrafluoroborate or [EMIM][BF_4], and 1-ethyl-3-methyl imidazolium ethyl sulphate or [EMIM][ETSO], was investigated for the extraction of acetonitrile from its binary mixture with benzene. Relevant ternary phase diagrams of acetonitrile + benzene with [EMIM][Tf], [EMIM][BF_4], or [EMIM][ETSO] were obtained based on refractive index results, with samples collected at 298.15 K under atmospheric pressure conditions. The distribution coefficient (D) and selectivity (S) of acetonitrile against the [EMIM] based ionic liquids were calculated to ascertain the separation efficiency. The data analysis reveals that [EMIM][BF_4] is the most efficient ionic liquid for the separation of acetonitrile + benzene binary azeotrope compared to [EMIM][Tf] and [EMIM][ETSO]. Two activity coefficient models, namely the NRTL and UNIQUAC equations, were further employed to correlate the experimental data, yielding satisfactory results, with the NRTL model performing slightly better than the UNIQUAC model..

Keywords: Ionic liquids; Azeotrope mixture; Distribution coefficient; Selectivity; Activity coefficient.

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Process Integration of Dark Fermentation and Microbial Electrolysis Cell to Enhance Hydrogen Production from Palm Oil Mill Effluent

Kai Yu Yong[1], Li Wan Yoon[1], Kai Ling Yu[1]

[1] School of Engineering, Faculty of Engineering and Technology, Sunway University, Malaysia

Corresponding Author: liwany@sunway.edu.my (L.W. Yoon)

ABSTRACT

Palm oil mill effluent (POME) is a high-strength organic wastewater that presents significant environmental challenges in Malaysia, yet it holds substantial potential for renewable biohydrogen (bio-H_2) production. While dark fermentation (DF) is widely used to convert POME into bio-H_2, its yield is often limited by the accumulation of volatile fatty acids. This study aims to determine the optimal pH for standalone DF and evaluate the integration of dual-chamber microbial electrolysis cell with DF as single-stage system (sDFMEC) to enhance bio-H_2 production and soluble chemical oxygen demand (SCOD) removal. Experiments were first conducted for standalone DF on raw POME at 37 °C and initial pH of 5, 6 and 7 to identify the optimal condition for maximising H_2 recovery. Subsequently, sDFMEC was operated at the optimal pH under different applied voltages of 0.6 V, 0.8 V and 1.0 V using a cation exchange membrane and carbon felt electrodes to evaluate bio-H_2 production and SCOD removal. Results indicated that mildly acidic conditions and with electrochemical assistance strongly favoured H_2 recovery where standalone DF at pH 5 achieved an optimal H_2 yield of 82.56 ± 17.04 mL-H_2/g-SCOD, production rate (HPR) of 35.17 ± 0.65 mL-H_2/L-POME.day and 7.41 ± 1.58% SCOD removal. Furthermore, introducing electrochemical assistance in the sDFMEC system significantly improved performance compared to the mixed-inoculum standalone baseline. An applied voltage of 0.8 V maximised the H_2 yield at 37.62 ± 10.03 mL-H_2/g-SCOD whereas 0.6 V optimised both HPR at 26.16 ± 2.79 mL-H_2/L-POME.day and SCOD removal at 12.97 ± 3.14%. This work demonstrates that integrating biochemical and electrochemical processes into a single-stage system effectively improves H_2 recovery from complex industrial effluent. This study provides a viable strategy for waste-to-energy conversion, contributing to circular economy, supporting national goals for decarbonising the industrial wastewater treatment sector and clean energy generation.

Keywords: Dark fermentation (DF); Microbial electrolysis cell (MEC); Palm oil mill effluent (POME); Biohydrogen; Single-stage process

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Temperature-inferred stoichiometric ratio control in extractive–reactive distillation

Xuan Liang Choo[1], Yu-Ying Chen[2], Hao-Yeh Lee[2], Zong Yang Kong[1], Jaka Sunarso[3]

[1] School of Engineering, Faculty of Engineering and Technology, Sunway University, Malaysia.
[2] Department of Chemical Engineering, National Taiwan University of Science and Technology, Taiwan.
[3] Research Centre for Sustainable Technologies, Faculty of Engineering, Computing and Science, Swinburne University of Technology, Malaysia.

Corresponding Author: savierk@sunway.edu.my (Z.Y. Kong)

ABSTRACT

This study investigates the dynamic controllability of an extractive–reactive distillation (ED–RD) configuration that has previously demonstrated total annual cost (TAC) reduction relative to the double-column reactive–extractive distillation (DCRED) system. The process separates a ternary wastewater mixture of tetrahydrofuran (THF), ethanol (EtOH), and water (H_2O) *via in situ* ethylene oxide (EO) hydration. Four control structures (CSs) are systematically developed and evaluated under ±10% perturbations in throughput and feed H_2O composition to assess dynamic operability. Conventional double- and triple-point temperature control strategies (CS1 and CS2) enable satisfactory recovery of THF purity but fail to maintain EtOH specification. This limitation arises from deviations in the EO/H_2O stoichiometric ratio, leading to incomplete EO hydration and contamination of the EtOH product by unreacted species. These findings reveal that precise regulation of the reactive stoichiometry is critical for ensuring product quality. To address this, CS3 introduces an internal composition analyser to directly manipulate EO feed rate, departing from conventional product-stream composition control. This configuration ensures complete EO hydration and restores EtOH purity. To eliminate reliance on costly composition analysers, CS4 proposes a rarely reported feedforward strategy that estimates composition indirectly from temperature measurements. A disturbance-dependent decision algorithm regulates the feedforward calculator, enabling precise estimation of the EO flowrate. The resulting control performance closely matches that of CS3, while CS4 offers a practical advantage through the elimination of costly composition analyser. Overall, the ED–RD system not only preserves its economic advantage over DCRED but also exhibits superior dynamic robustness and operational stability. These results demonstrate that economically intensified distillation–reaction systems can be rendered industrially viable through strategically designed advanced process control.

Keywords: Stoichiometric ratio control; Extractive distillation, Reactive distillation; Dynamic controllability; Process intensification