WORKSHOP Geopolymer for Environmental Remediation

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GEA Geopolymer based Adsorbents

Engineering of eco-sustainable geopolymer-based adsorbent materials for the removal of emerging pollutants and environmental remediation

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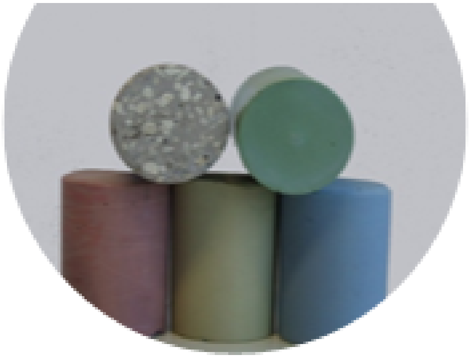
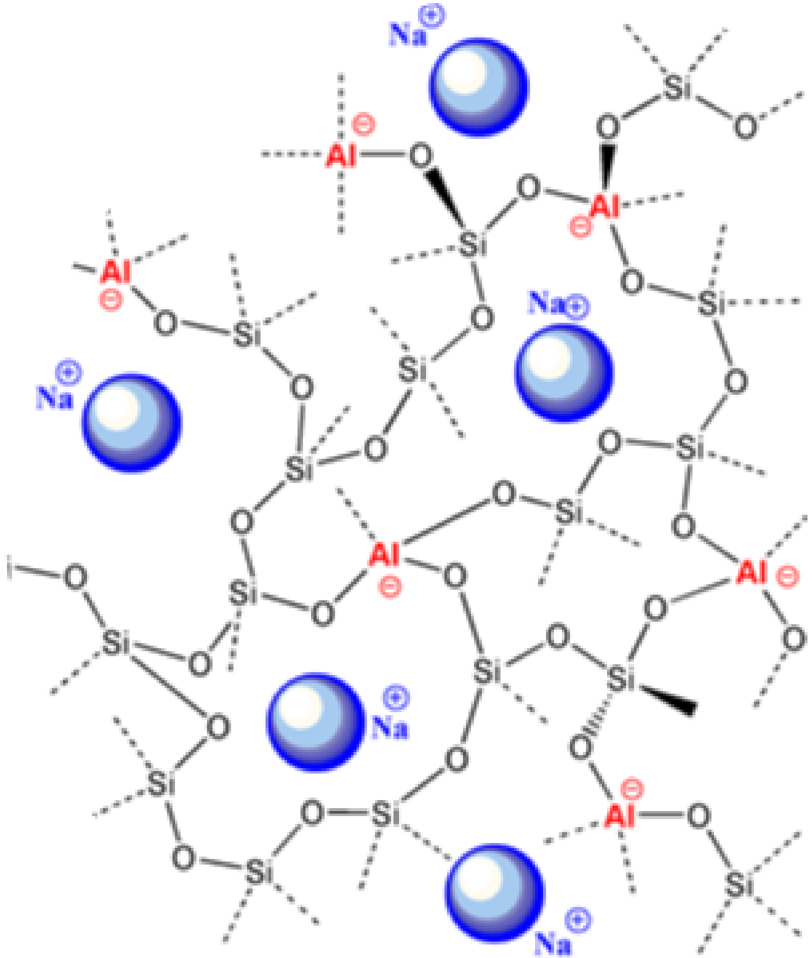


Geopolymers



Environmentally friendly material

- *Green* synthetic approach:
  - water-based synthesis
  - ...from largely available materials (e.g. clays)
  - ...from secondary raw materials (wastes)
  - Obtained @ low temperature (max 80°C)
- Reusable & Recyclable

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Applications (1)

- Building & construction:
  - Precast concrete
  - Pavements
  - Sewer pipes
- Cultural heritage
- ...

Source: https://www.geopolymer.org/news

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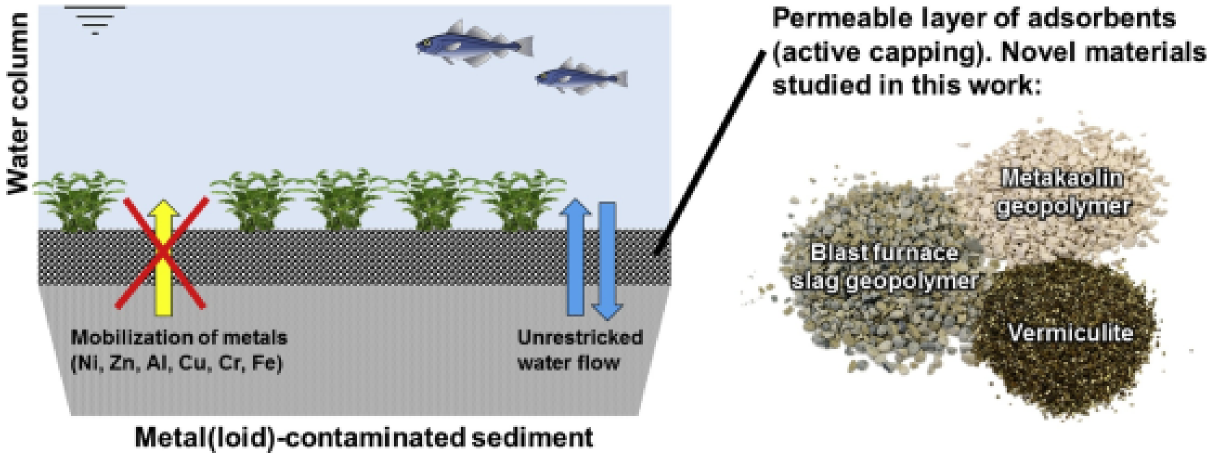
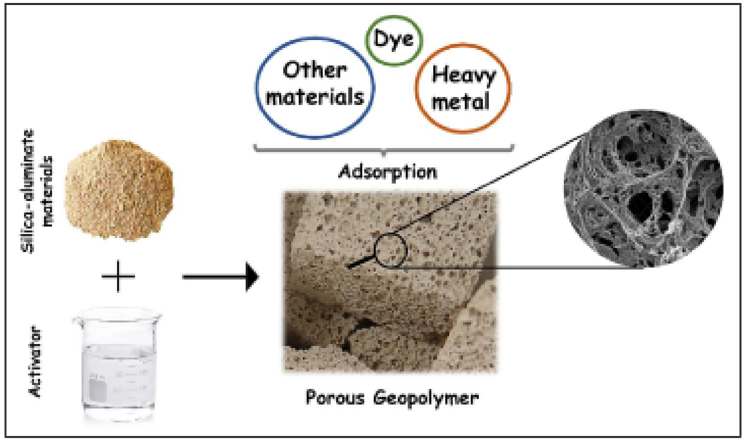
Applications (2)

- Adsorption of inorganic and organic contaminants in water.



- Environmental (*in situ*) remediation.



Source: Kutuniva et al. Journal of Environmental Chemical Engineering, 2019, 7,102852, https://doi.org/10.1016/j.jece.2018.102852.
Ettahiri et al. Construction and Building Materials, 2023, 395,132269, https://doi.org/10.1016/j.conbuildmat.2023.132269.

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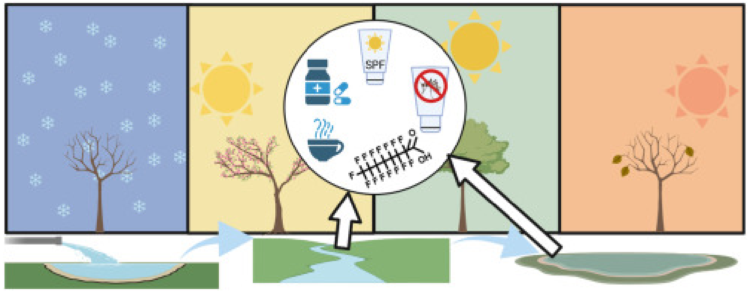
Emerging contaminants (CECs)

CECs are chemical substances that are not yet fully regulated but may have environmental and health impacts.

- Pharmaceuticals and antibiotics
- Personal care products (e.g., cosmetics, sunscreens)
- Pesticides and herbicides
- Microplastics
- Hormones and endocrine disruptors



- Sources of Pollution:
  - Urban and industrial wastewater
  - Agriculture and livestock
  - Household discharges
- Risks and Impacts:
  - Toxicity to aquatic ecosystems
  - Potential bioaccumulation in organisms
  - Unknown effects on human health
- Challenges and Solutions:
  - **Improvement of water treatment systems**
  - Stricter monitoring and regulation
  - Reduction in use and sustainable alternatives

https://www.epa.gov/wqc/contaminants-emerging-concern-including-pharmaceuticals-and-personal-care-products

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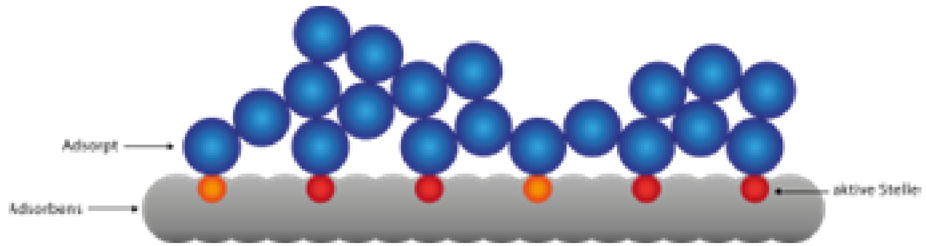
Adsorption



- Adsorption processes are among the **most effective methods for CEC removal**, offering high efficiency, low operational costs, and no harmful by-products.
  - A surface-based process where molecules from a liquid or gas adhere to the surface of a solid material (adsorbent).
  - Pollutants interact with the adsorbent through physical (Van der Waals forces) or chemical bonding.
  - Common materials include **activated carbon**, biochar, zeolites, and metal-organic frameworks.

- Limitations & Challenges:
  - Need for effective regeneration and disposal methods,
  - High costs associated with some advanced adsorbents,
  - Competition between different pollutants, which can reduce adsorption efficiency.

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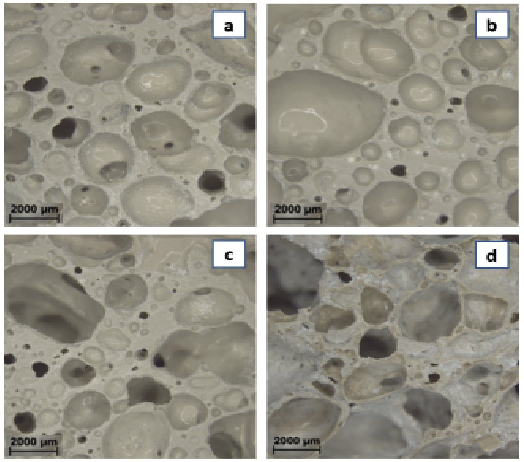
Engineering of eco-sustainable geopolymer-based adsorbent materials for the removal of emerging pollutants and environmental remediation

Aim: development and use of geopolymer based materials for the adsorption of CECs.

1. Development of
   a) large-scale, sponge-like continuous filters via direct foaming, creating 3D reusable monolithic adsorbent structures with high surface area.
   b) porous spheres to be used in columns for continuous treatment of wastewater
2. Incorporation of zeolitic domains to enhance the adsorption capacity of the geopolymer itself, towards cationic, anionic, and neutral species.
3. Functionalization of the material surfaces to enhance adsorption capacity and, by introducing catalytically active species, to enable *in situ* and/or continuous degradation of the adsorbed pollutants.



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Some preliminary results

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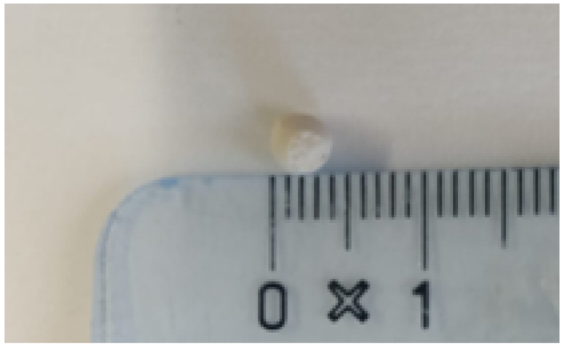
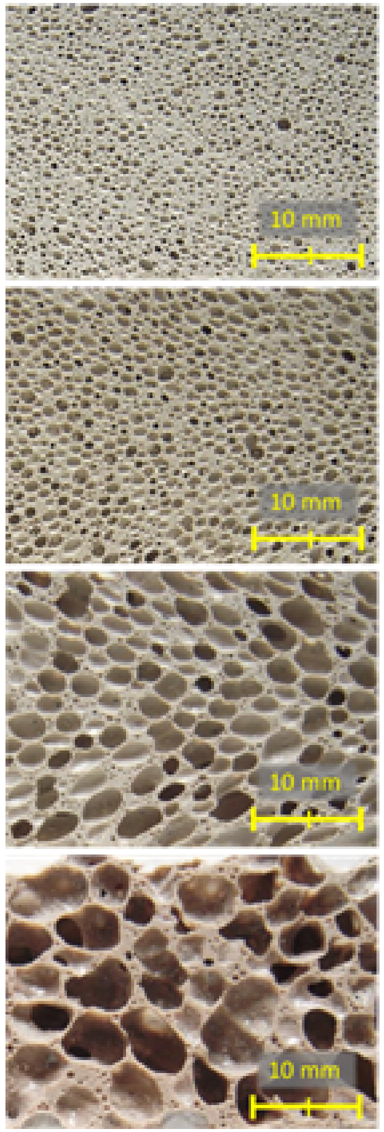
Porous artifacts from different raw materials and with tailored porosity





Migliaccio, Falzarano, Roviello, Ferone, Tarallo, **2025**, manuscript in preparation

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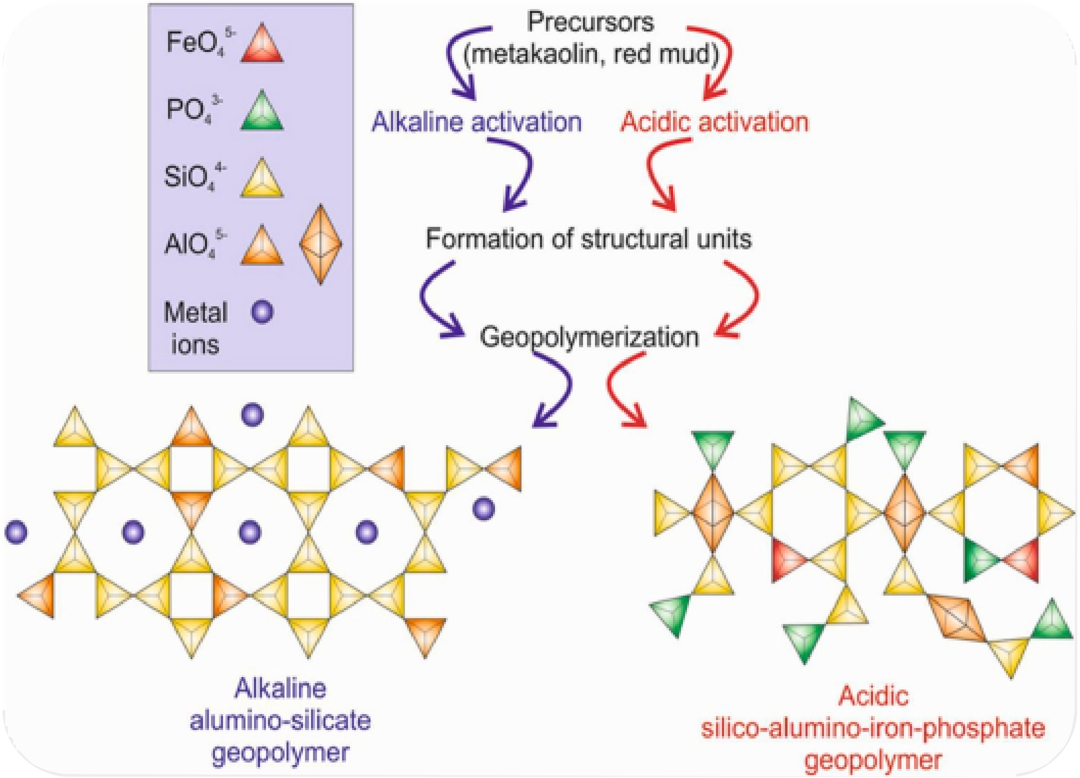
Alkaline and acid geopolymers

Geopolymers share a similar composition with zeolites; however, unlike zeolites, geopolymers possess an amorphous structure. Like zeolites, they are typically synthesized from aluminosilicate precursors through polycondensation in either an alkaline or acidic environment.

ALKALINE GEOPOLYMERS

Activating solution: Sodium silicate (SS)

Alkaline activation causes sodium (Na^+) to balance the negative charges that form on the Al tetrahedral complex.



ACID GEOPOLYMERS

Activating solution: Phosphoric acid 10M (HP)

Acid activation allows the production of poly(silicon-aluminum-phosphate) characterized by $[AlO_4]^{5-}$, $[SiO_4]^{4-}$, $[PO_4]^{3-}$ and $[FeO_4]^{5-}$ units.

Occhicone et al., *Journal of Cleaner Production*, **2024**, *435*, 140492.

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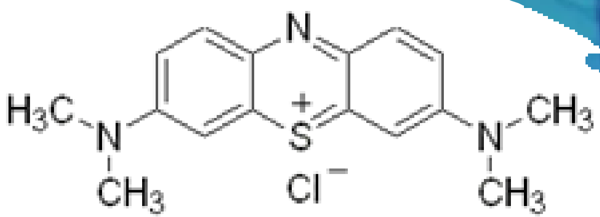
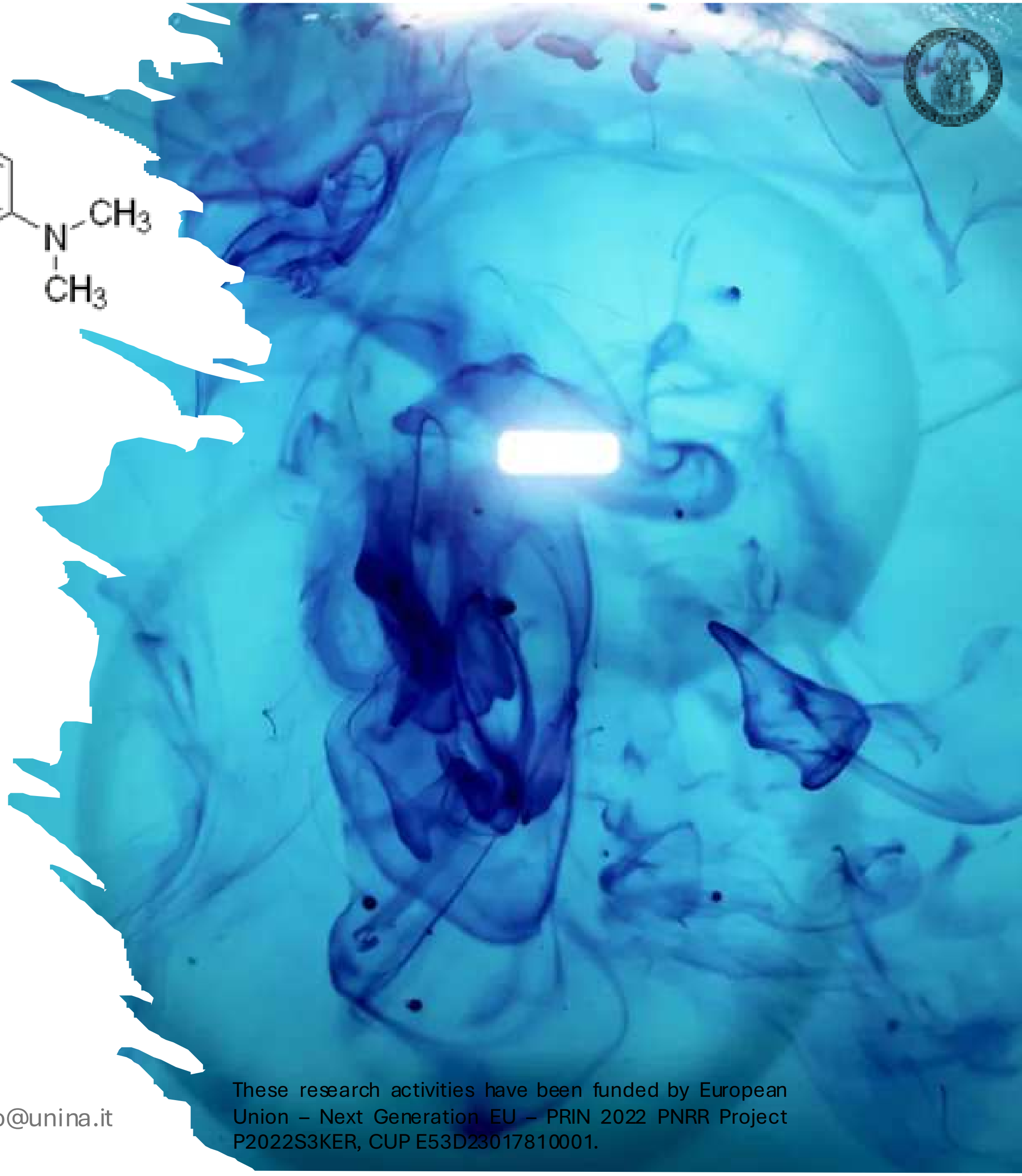
Methylene Blue



- Methylene blue (MB) is an emerging contaminant often detected in wastewater due to its widespread use in industries like textiles and medicine.
- Its persistence and toxicity pose significant environmental and ecological risks, necessitating effective removal strategies.
- Additionally, MB is commonly used as a **model dye in adsorption experiments** due to its well-known chemical properties and ease of detection.
- **Its molecular structure and cationic nature make it ideal for evaluating the adsorption efficiency of materials like geopolymers.**



Hmoudah, Roviello, Tarallo, et al., **2025** ,submitted

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Methylene Blue & Geopolymers

- **Composite geopolymers with graphene and graphene derivatives** have been developed to improve the adsorption performance of MB, by leveraging potential synergistic effects.
- A detailed **kinetic characterization** was carried out to gain deeper insights into the adsorption process, along with an analysis of **adsorption isotherms**.
- These investigations aim to better understand the **adsorption mechanisms** and assess the potential applicability of the developed composite materials.

Cesaro, Roviello, Tarallo, et al., **2025** manuscript in preparation

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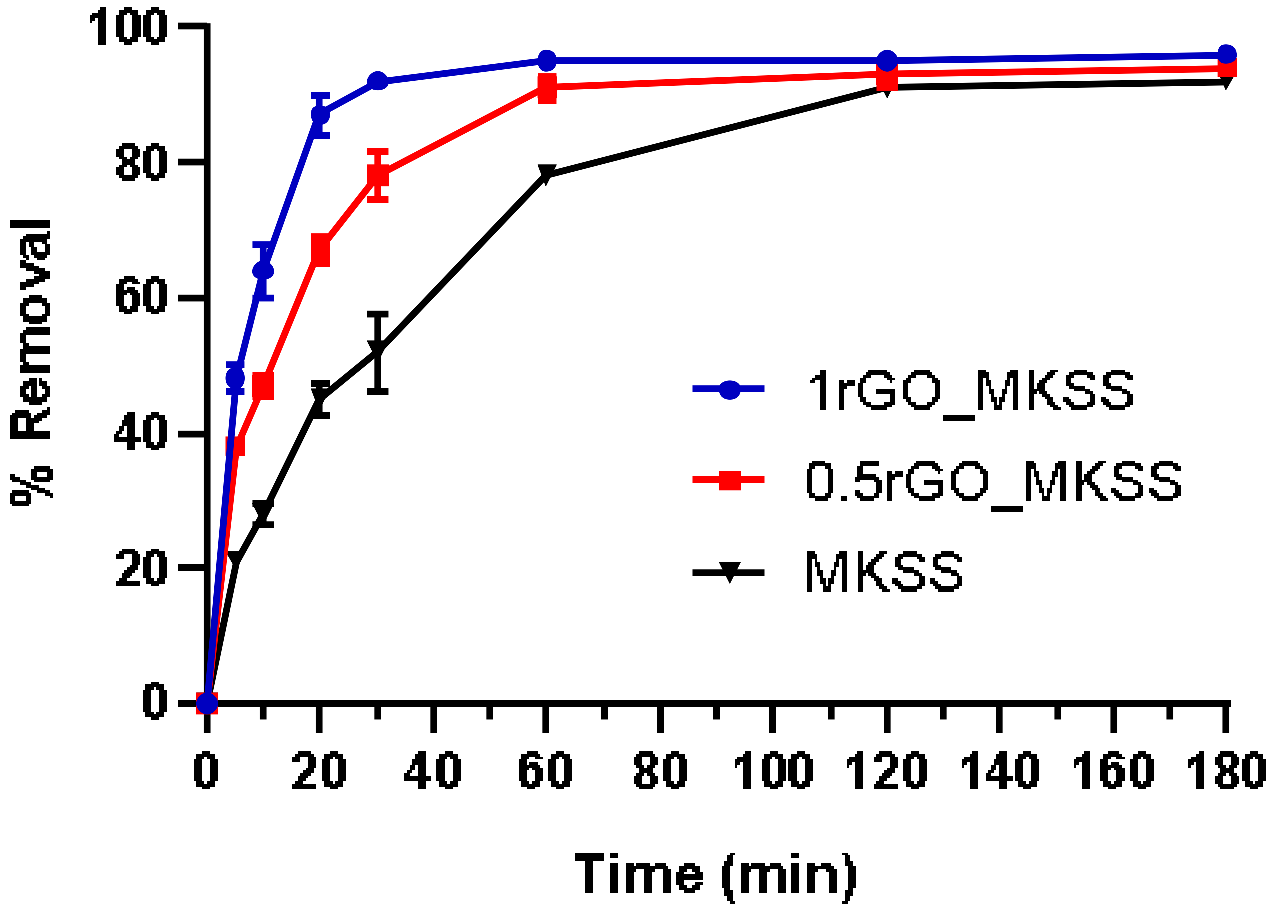
MB adsorption kinetics

- Neat Geopolymer (MKSS) displayed the slowest adsorption kinetics and lower overall efficiency
  - 90% removal after 120 minutes.
- Composite containing 1%wt of rGO (GO1%_MKSS) exhibited the fastest removal efficiency
  - 98% within the first 60 minutes.
  - rGO, enhances the surface area and adsorption capacity facilitating physical adsorption.



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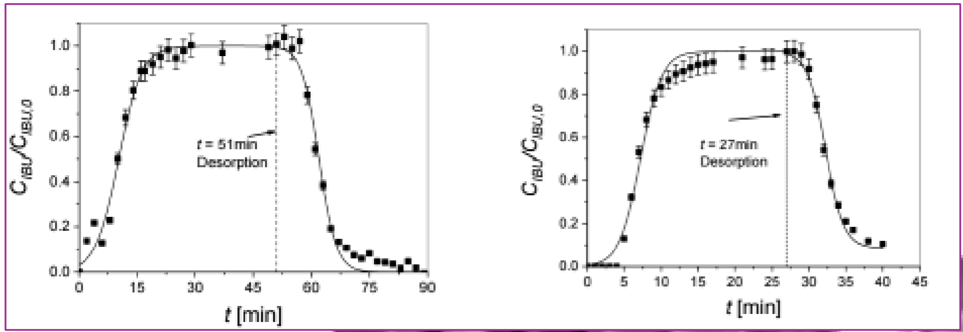
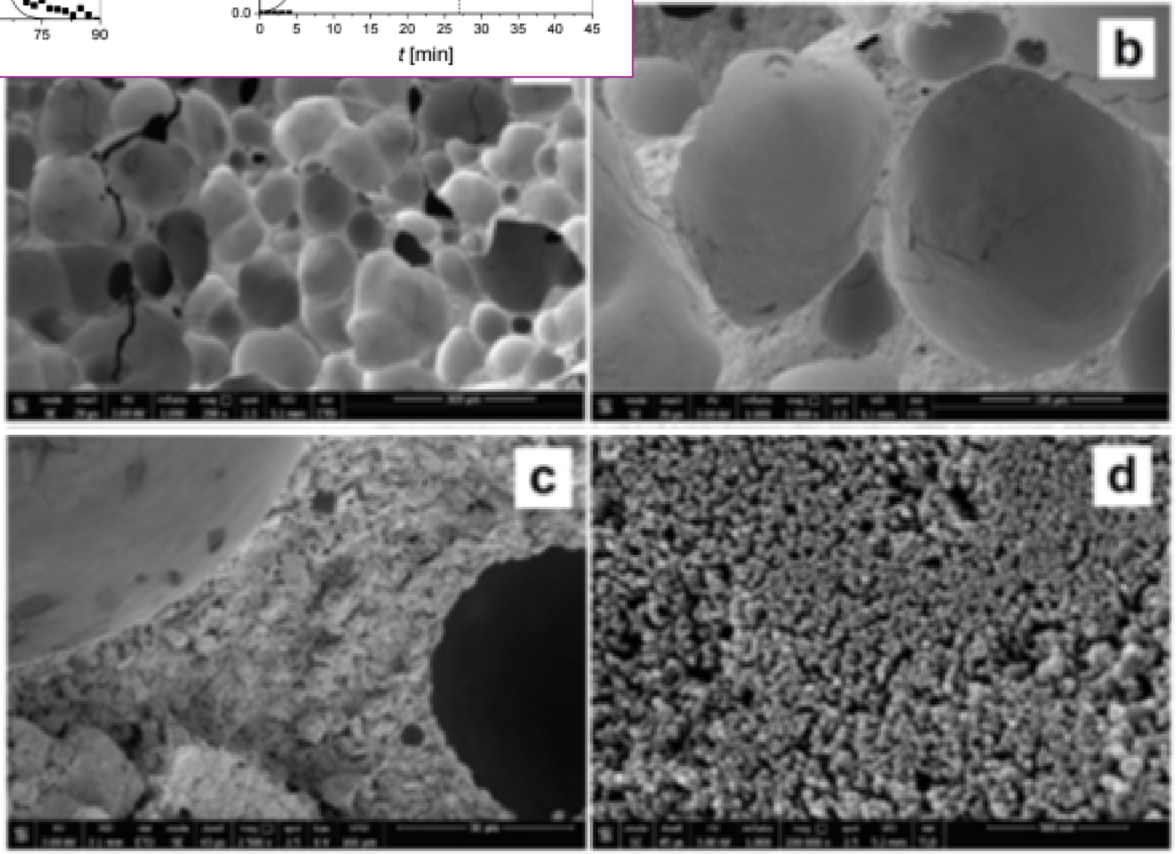
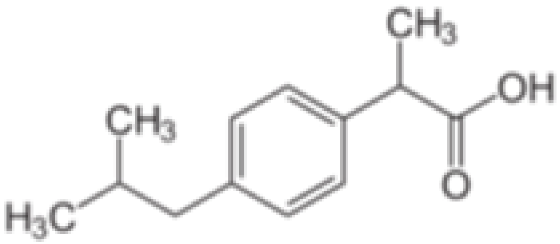
Ibuprofen



- IBU concentration decrease up to 30% in batch and removal percentage of about 90% in continous





Paparo, Roviello, Tarallo et al., *Molecules* **2024**, *29*, 2210.

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