Karlsruhe Institute of Technology

VIRTUAL MATERIALS DESIGN

Institute of Functional Interfaces (IFG)
Institute of Nanotechnology (INT)

Digital twin of methacrylate-based multi-modal chromatography resin

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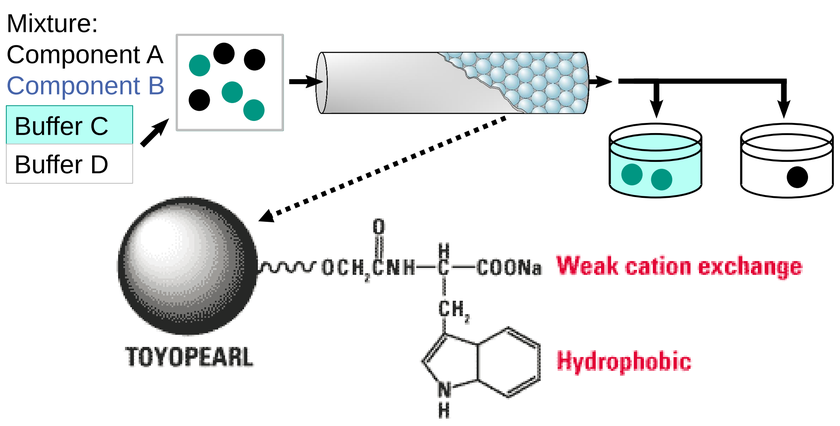
Multimodal chromatography resin such as the commercial TOYOPEARL MX-Trp-650M can be used to separate, purify or remove (bio-)chemical compounds from a mixture. Adsorption of the target compound onto the polymeric network correspond to complex interaction schemes including steric exclusion, H-bonding, salt bridges etc., when the selectivity of resin can be adjusted with external control parameters such as elution conditions such as pH. In parallel with high-throughput experiments, a digital twin of the chromatography resin enables computational screening in binding and elution conditions for prospective adsorbents. As proof-of-concept for Metanil Yellow dye, computational adsorption isotherm yields a record-breaking accuracy when the *in silico* workflow provides "one-click" solution to predict binding performances of larger compounds as proteins.

Selective compound separation

Distinguished adsorption properties of the chromatography resin with respect to guest molecules. When adsorbed, buffers e.g. with unique pH, can "wash" target molecules off the chromatography resin with high selectivity. Switching buffers amid different adsorbing-washing cycles, target compounds can be separated.

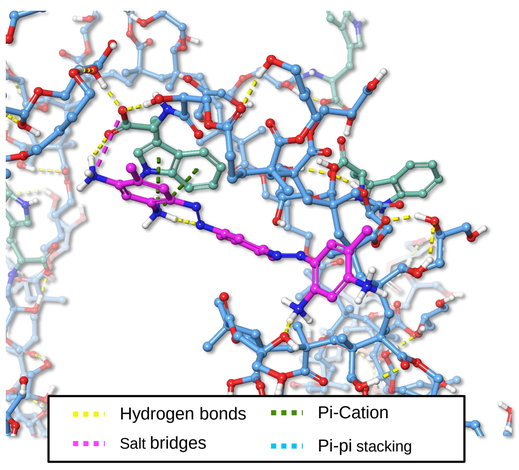


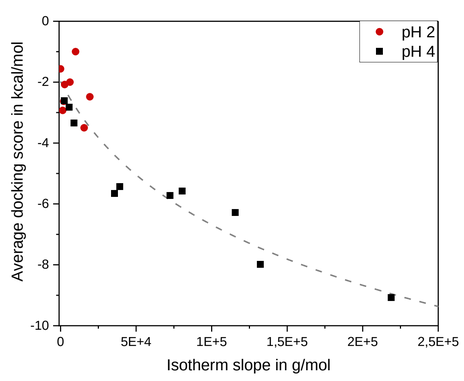
Exact chemical composition of commercial multimodal resin from TOYOPEARL is unknown, however an approximate polymer network model built from DHPMA + EGDMA + Trptophan + porogen can be established by computational molecular construction.

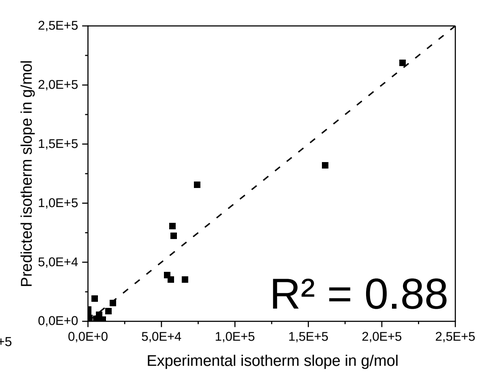
Digital twin of guest@TOYOPEARL

To build the chromatography resin in the form of a polymer network, a coarse-grained molecular dynamics scheme incorporating prescribed polymerization reactions comparable to 3D printing,[1] is later "back-mapped" to the all-atom representation.

The atomistic polymer network is thereafter incorporated into docking simulations with the target adsorbent, to determine the binding energy, which is also dependent on buffer conditions. The simulated binding energies are fitted to an adsorption isotherm in very good agreement with experimental results.

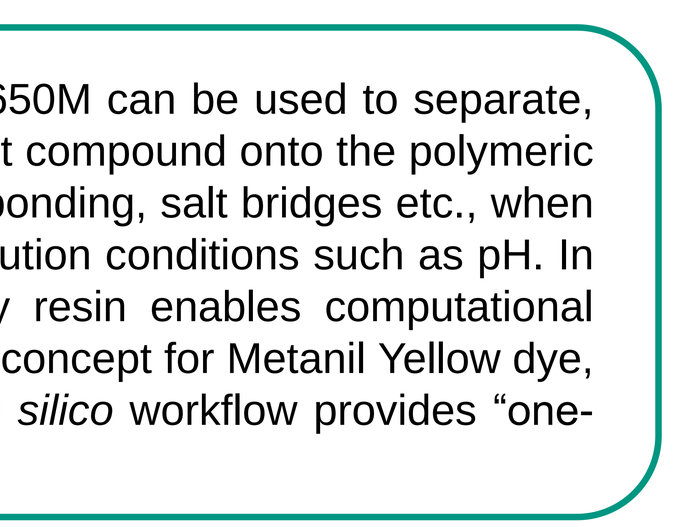






High-throughput workflow

"One-click" solution to polymer network generation with customizable chemical composition, density, and dimensions is implemented using SimStack engine.[2]



Conclusion & Outlook

- For a multimodal chromatography resin from TOYOPEARL, a digital twin as a DHPMA + EGDMA + Trp polymer network is established. In the benchmark of adsorbing Metanil Yellow, the computational model yields very high accuracy.
- An automated workflow to generate polymer network structures, coupled with docking simulations allow for high-throughput investigation of additional adsorbent x condition combinations. The next goal is to scale up and test the workflow with protein.

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References:
[1] *Nat. Commun.*, **13**, 2022
[2] *Front. Mater.*, **9**, 2022