Facile nanomaterial coated 3D printed spacer architectures for effective scaling control in membrane systems

Navya Thomas[1,2], Mahendra Kumar[1], Giovanni Palmisano[1], Rashid Abu AlRub[1], Reham Nuaimi[1], Emad Alhseinat[1], Reza Rowshan[3], Hassan Arafat[1]

[1] *Technology Innovation Institute, Abu Dhabi, United Arab Emirates*
[2] *Khalifa University, Abu Dhabi, United Arab Emirates*
[3] *New York University - Abu Dhabi Campus, Abu Dhabi, United Arab Emirates*

Navya.Thomas@tii.ae

In recent explorations of membrane-based desalination, innovative spacer designs and surface modifications are emerging as powerful tools to combat scaling, a persistent challenge in water treatment [1]. This study investigates the potential of 3D-printed, highly engineered spacers with advanced 2D nanomaterial coatings to enhance flux performance and mitigate scaling in membrane distillation (MD) systems. By utilizing 3D printing, we can create custom-designed spacer architectures that optimize flow within membrane channels, achieving both high flux rates and lower pressure drops. These uniquely structured spacers enhance flux by up to 50% compared to conventional mesh designs in MD process [2]. Further enhancing their effectiveness, we modified the surface chemistry of these 3D-printed spacers with nanomaterial coatings, including graphene, graphene oxide, reduced graphene oxide, and fluorinated silica nanoparticles. These coatings adjust surface properties such as wettability and free energy, introducing functional groups that alter spacer interactions with scalants. Coatings with graphene and fluorinated silica nanoparticles, in particular, create a micro-rough, hydrophobic surface texture with reduced surface energy, thus weakening the attachment of scalants at membrane-spacer contact points and lowering membrane scaling. The nanomaterial-coated spacer demonstrated a 74% reduction in scalant attachment compared to the uncoated spacer [3]. The integration of flow-optimized design and surface engineering showcases the role of nanomaterial coatings in enhancing performance, demonstrating how a spacer-centric approach can complement traditional membrane-focused strategies in desalination applications.

References

[1] Sreedhar, N. et al., Desalination, 554 (2023), pp.116505.
[2] Thomas, N. et al., Journal of Membrane Science, 581 (2019) pp.38-49.
[3] Thomas, N. et al., Water Research, 189 (2021), pp. 116649.

Figures

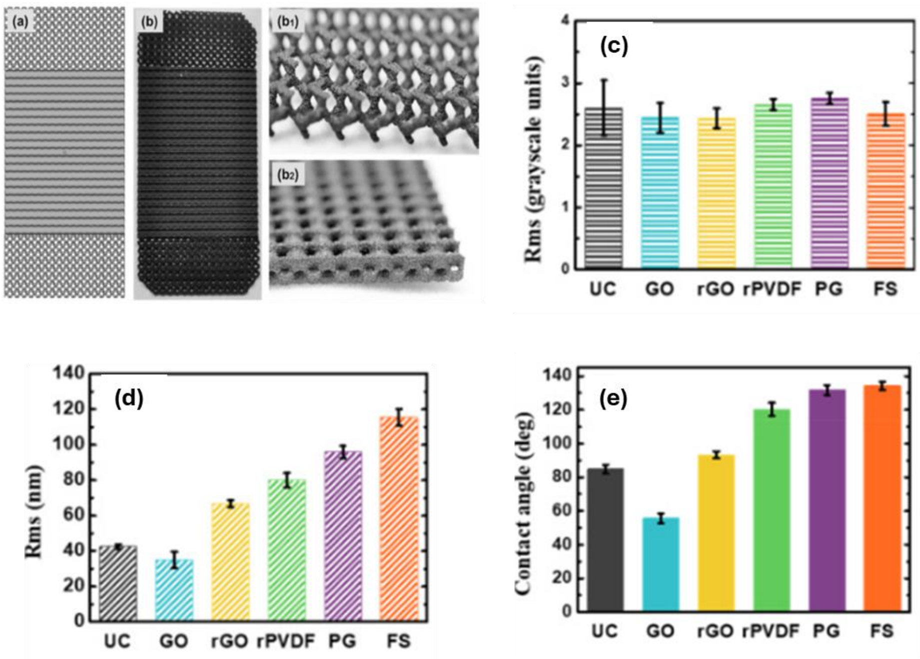

Figure 1: (a) Orthographic CAD drawing, (b) photographic image of the hybrid (Gyr-tCLP) 3D printed TPMS spacer, zoomed photographic images of (b1) Gyroid and (b2) tCLP architectures; comparison of the (c) macro-roughness, (d) micro-roughness, (e) contact angle measurements of nanomaterial coated and uncoated surfaces (UC – uncoated, GO – graphene oxide, rGO – reduced graphene oxide, PG – pristine graphene, FS – fluorinated silica).