News & views

Flow photocatalysis

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Putting porous nanofluids in motion

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Continuous-flow photocatalysis is frequently hindered by the need to reconcile light absorption, mass transfer, and catalyst recovery, reflecting a fundamental trade-off between molecular efficiency and operational practicality. Now, a study shows that stable covalent organic framework (COF) nanofluids combine structural definition with dynamic mobility. This design enables rapid and scalable achiral and chiral oxidation reactions, as exemplified by the minute-scale production of artemisinin.

Photocatalysis under continuous-flow conditions has emerged as a powerful platform for sustainable chemical synthesis, offering precise control over light penetration, residence time, and process scalability[1]. Yet, its broader adoption remains constrained by a persistent dilemma. Homogeneous photocatalysts generally enable efficient photon absorption and rapid mass transfer, but their separation and reuse remain challenging[2]. In contrast, heterogeneous systems provide operational robustness and catalyst recyclability, albeit often at the expense of photon utilization and transport efficiency[3,4]. These trade-offs become particularly acute in microreactors, where high surface-to-volume ratios amplify both the advantages and the limitations of each regime. In addition, packed-bed flow photocatalysis is frequently hindered by limited light penetration, while the use of mobile heterogeneous photocatalysts can lead to potential clogging. Consequently, combining the efficiency of homogeneous photocatalysis with the practicality and recyclability of heterogeneous systems, while avoiding clogging, remains a central challenge in modern flow chemistry, particularly for applications requiring both high performance and scalability.

Now, writing in *Nature Catalysis*, Cui, Liu, Zhu, Su and co-workers present a compelling solution: porous COF nanofluids that function as dispersed yet structurally defined photocatalysts under continuous-flow conditions[5]. Rather than immobilizing catalysts on reactor walls or confining them within packed beds, this strategy transforms crystalline porous frameworks into stable colloidal dispersions without clogging. In doing so, catalysts gain fluidity while retaining permanent porosity and crystallinity, effectively blurring the conventional boundary between homogeneous and heterogeneous catalysis and establishing a hybrid operational regime.

To realize this concept, the researchers engineer ionic COFs bearing Ru(II)–triphenanthroline photocatalytic units within triple-helix porous architectures, resolved at near-atomic precision by cryogenic low-dose electron microscopy. Shear processing yields ~100 nm, surfactant-free nanofluids stabilized by electrostatic repulsion (Fig. 1a), which remain colloidally stable over extended periods, combining molecular-level catalytic precision with nanoscale mobility and macroscopic flow compatibility. This unique convergence of crystallinity and dynamic dispersibility is central to overcoming the mass-transport limitations that typically constrain heterogeneous photocatalysis.

These features translate directly into enhanced catalytic performance. In a slug-flow photomicroreactor, the COF nanofluids exhibit improved light penetration, heat dissipation, and mass transport compared to bulk COFs and homogeneous analogues. This advantage is exemplified in the semi-synthesis of artemisinin, which reaches 64% yield within seven minutes under continuous-flow, substantially outperforming conventional systems[6] (Fig. 1b). The platform further demonstrates broad applicability, enabling rapid aerobic oxidations within minutes. Notably, coupling a chiral small-molecule catalyst with the uniformly dispersed photocatalytic nanofluid enables tandem photooxidation–asymmetric Mannich reactions to proceed with both high yield and enantioselectivity. Such examples of asymmetric photocatalysis in continuous flow remain rare, underscoring the inherent challenge of simultaneously achieving precise stereocontrol and efficient photon utilization[7].

Equally important is the demonstration of scalability. By implementing a dual-capillary microreactor design, the researchers achieve straightforward numbering-up, doubling production rates without sacrificing efficiency and enabling continuous operation and gram-scale throughput. Unlike conventional packed-bed systems, which are prone to pressure buildup, channel blockage, and catalyst deactivation, the nanofluid-based system maintains low pressure drops and stable operation over extended timescales. As such, this strategy aligns naturally with industrial flow chemistry and provides a practical pathway from laboratory discovery to manufacturing-relevant processes.

Taken together, this work positions porous nanofluid photocatalysis as a promising avenue for flow chemistry. It replaces the traditional dichotomy between homogeneous and heterogeneous catalysis with a continuum defined by structural order and dynamic dispersion, where nanoscale motion, interfacial transport, and reactor hydrodynamics collectively govern performance. By integrating catalyst design with process engineering, the study shows that reactivity can be enhanced not only through molecular innovation but also through precise control of transport and flow. More broadly, porous nanofluids point toward catalytic systems in which structure and dynamics are co-optimized across materials and process scales.

Looking ahead, expanding the structural diversity of COF nanofluids – through tailored chromophores, redox-active metal centres, and chiral functionalities – could unlock a broader spectrum of photocatalytic transformations, particularly more sophisticated asymmetric processes. Concurrently, precise control over particle size, porosity, and colloidal stability will be crucial for optimizing photon transport and preventing clogging under micro-flow conditions. The integration of nanofluid catalysts with advanced reactor engineering – spanning microfluidic architectures, photonic designs, and AI-enabled automated flow platforms – offers further opportunities to enhance performance through real-time optimization and adaptive control[8].

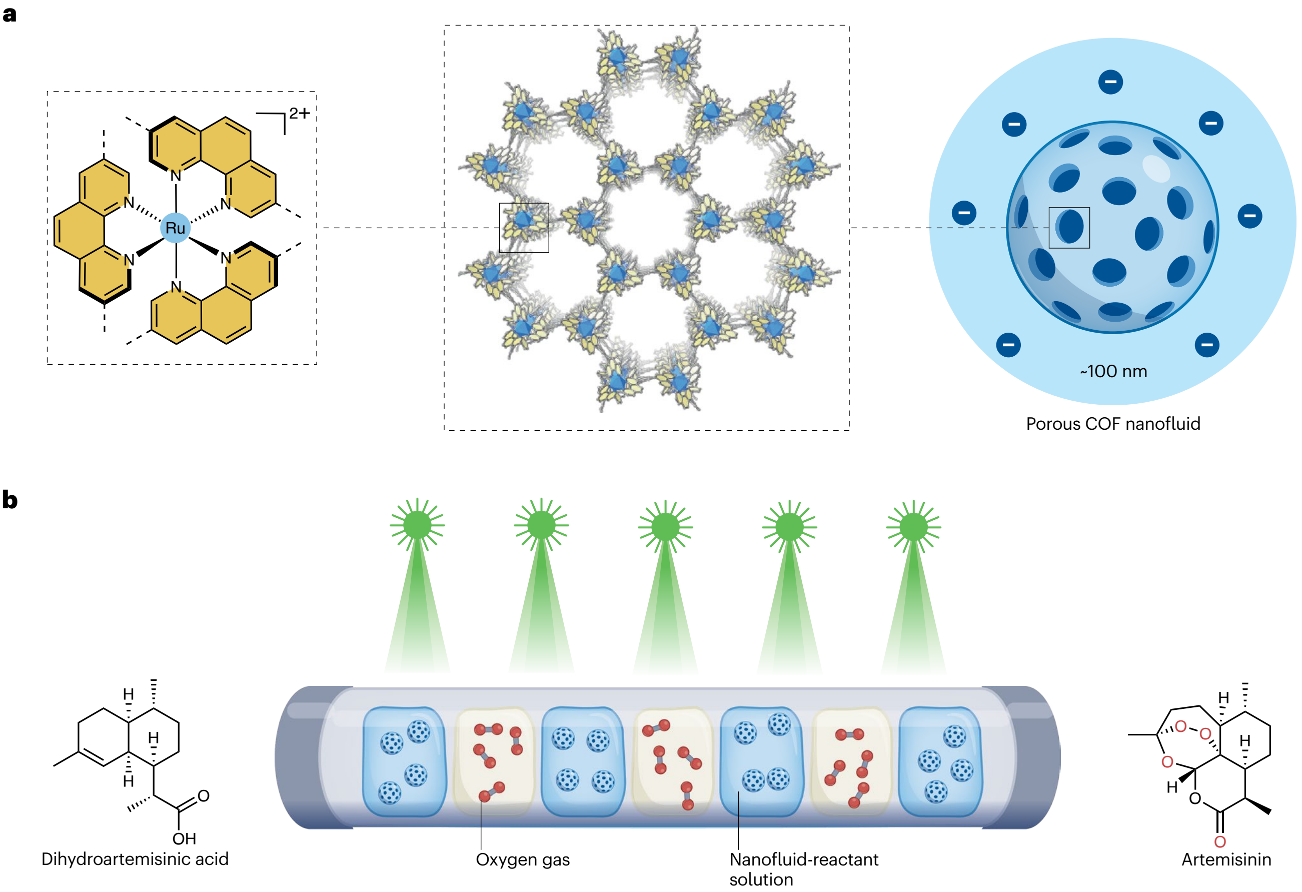

Fig. 1 | Porous COF nanofluids for continuous-flow photooxidation. **a**, Schematic illustration of a Ru-based metallolinker assembled into a crystalline COF and dispersed as ~100 nm porous nanofluid particles for enhanced accessibility and transport. **b**, Segmented gas–liquid continuous flow of COF nanofluids enables efficient photooxidation of dihydroartemisinic acid to artemisinin. Adapted from ref. 5, Springer Nature Ltd.

In this context, computational modelling, digital twins, and machine learning-driven workflows are poised to play an increasingly important role in understanding and orchestrating multiphase flow, heat transfer, and photon distribution across scales.

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Competing interests

The authors declare no competing interests.