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Preying on pollutants

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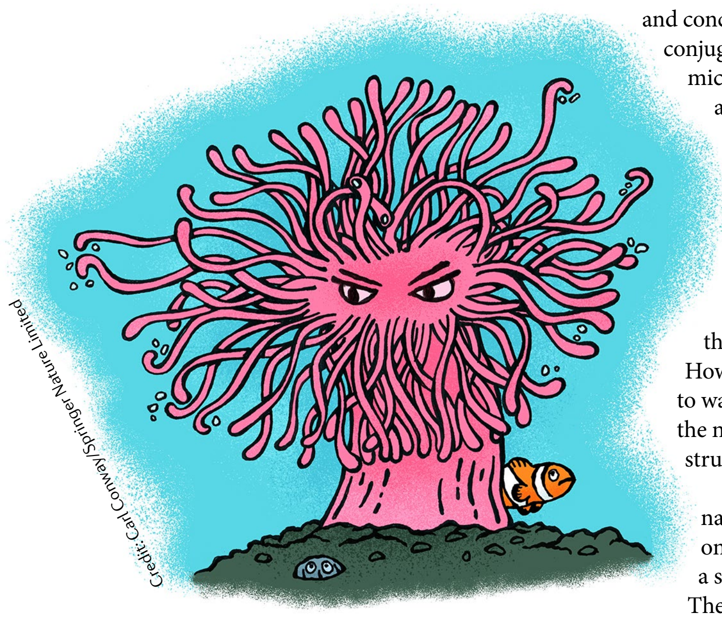
The purification of wastewater is one way of tackling the global scarcity of water. To meet water-quality standards, a wide range of pollutants — including colloidal particles and dissolved contaminants — must be removed, often requiring slow and expensive multistep treatment processes. Now, reporting in *Nature Nanotechnology*, Menachem Elimelech, Huazhang Zhao and co-workers introduce a biomimetic nanocoagulant that can remove diverse contaminants from wastewater in a single treatment step.

Coagulation is typically one of the first steps in advanced water-treatment processes. "Conventional coagulants destabilize colloidal particles into precipitates through charge neutralization and enmeshment, but they are mostly ineffective in removing small dissolved contaminants," remarks Zhao. However, the development of a coagulant that can simultaneously remove dissolved contaminants and suspended particles is challenging. "Introducing multiple components into a single coagulant can induce precipitation during preparation and long-term storage, thus negating its ability to stably disperse in water," explains Jinwei Liu, first author of the study. Taking inspiration from the marine predator *Actinia* (a genus of sea anemones), which captures its prey using tentacles that are otherwise retracted, the team designed a micellar nanocoagulant with a core–shell structure that mimics the eversion behaviour of *Actinia*. The 'nano-predator' shows excellent long-term stability at low pH and the unprecedented ability to simultaneously capture diverse contaminants.



Acid–base self-assembly is used to prepare the nanocoagulants: the organic component, a trimethoxysilyl quaternary ammonium with long carbon chains, is first hydrolysed and then reacted with the inorganic component, $AlCl_3$. Through careful control of the pH, reactant ratios and concentrations, the resultant conjugates assemble into micellar structures with an aliphatic quaternary ammonium core and an outer shell comprising charged Si–Al complexes. This configuration, with the aliphatic 'tentacles' retracted, is similar to the resting state of *Actinia*. However, upon exposure to wastewater with a pH $\geq$ 4, the nanocoagulant everts its structure, exposing its core.

The efficacy of the nanocoagulant was tested on wastewater effluent from a sewage-treatment plant. The nanocoagulant reduced turbidity by >90% but also removed >90% of dissolved organic carbon, total phosphorus and nitrate. By contrast, typical industrial coagulants (such as $Al_2(SO_4)_3$) substantially reduced turbidity but demonstrated much lower removal efficiencies of dissolved organic carbon (30–54%) and total phosphorus (8–68%) and negligible removal of nitrate. Moreover, unlike the conventional coagulants, the nanocoagulant also exhibited high removal efficiencies of trace organic micropollutants and pharmaceuticals. The ability of the nano-predator to entrap a wide range of waste pollutants is attributed to its unique eversion behaviour. "During coagulation, the outer shell destabilizes and enmeshes large colloidal contaminants while the exposed core captures small dissolved contaminants," explains Zhao.

Proof-of-concept demonstration of a multifunctional nanocoagulant is a step towards the realization of more efficient water-treatment processes. "Coagulation, which has been around for centuries, could evolve into a premier water-treatment process that is a simple and cost-effective replacement for some current water-treatment practices," says Zhao. Moreover, the team envisage that the eversion response of their nano-predator could inspire the development of functional 'smart' materials that can adapt their configuration and function for a wide range of applications.

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