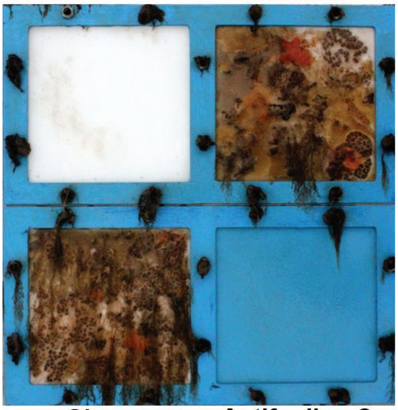
Slippery Liquid-Infused Porous Surfaces

by Joanna Aizenberg

Marine biofouling, the process of accumulation of microorganisms, plants, algae and animals on submerged surfaces, is an age-old problem associated with any maritime activity affecting commercial and recreational shipping activities, naval operations, aquaculture facilities and marine renewable energy structures alike. The adverse effects of marine biofouling include the increase of drag on ship hulls, damage to ships and maritime equipment such as corrosion, the spread of diseases in aquaculture and the distribution of invasive species causing extensive damage to coastal ecosystems and the benefits derived from them. An estimated global annual total of $60 billion in fuel cost alone can be saved by the application of marine antifouling coatings, making the treatment of marine biofouling a necessity not an option.

Before 2003, tributyltin (TBT) based self-polishing coatings were widely applied to ship hulls, as this treatment effectively prevented the settlement and establishment of marine fouling communities for a sufficient period of time. However, as the evidence of widespread ecosystem damage due to the highly toxic leachates from TBT coatings became more and more apparent, this compound was slowly phased out and eventually globally banned in 2008. Since then, there has been a fallback to copper-based self-polishing paints, which were predominant before the rise of TBT in the late 1970s. While being slightly less toxic than TBT, copper-based compounds are less effective. The performance of copper-based coatings is further challenged by the development of resistance to copper in marine fouling organisms such as in the barnacle *Amphibalanus Amphitrite*, which have become increasingly common in harbours and marinas. There has been a series of efforts for more stringent regulations and even bans of copper-based coatings in the United States and Europe in recent years, as these coatings have also been linked to the deterioration of marine environments.



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These coated settlement tiles were in the water for two months at the field test site located at Cohasset Harbor, Massachusetts. SLIPS completely prevented the establishment of a macrofouling community.

These developments have led to a renewed interest in the development of non-toxic marine coatings that rely on the surface-slippage and release of attached marine organisms. This is the area where the application of SLIPS (Slippery Liquid-Infused Porous Surfaces) – a revolutionary technology that won a R&D100 award in 2012 – can be a game changer. Developed by the Harvard team, this bio-inspired concept is mimicking antifouling strategies employed by nature, such as mucus-coated fish scales, slime-coated algae fronds or slippery, insect-catching surfaces of pitcher plants. SLIPS is based on the combination of a properly designed porous substrate infused with an inert, water-insoluble, non-toxic liquid lubricant that forms an immobilized, slippery, liquid overlayer on top of any solid substrate. In addition to dramatically increasing surface-slippage, this overlayer fundamentally changes the interactions between the fouling organisms and the substrate, as the organisms are now confronted with a mobile and an atomically smooth liquid surface instead of a stationary, easy-to-attach solid surface.

Recent studies have shown that SLIPS can effectively repel any type of liquid (aqueous or organic), microorganisms, insects and ice, making it a platform technology for a wide range of applications. More recent investigations have also shown promising antifouling performance against the fouling of a range of marine organisms both in the laboratory and in the field, combined with excellent anti-corrosive properties. This is an indication that SLIPS can also be applied to marine fouling problems. SLIPS can be made from a wide range of base materials and lubricants, which allows for customized materials design that can be tailored for very specific applications. For example, the SLIPS can be made transparent for the coating of underwater camera lenses and sensors. SLIPS can be made flexible for sonar equipment and hydrophone cables that suffer extensively from calcareous hard fouling affecting the signal transmission and reception. Additionally to the development of coatings for moving vessels, SLIPS can be applied to more stationary marine equipment in low flow environments, such as marine aquaculture facilities that suffer from the build-up and decay of short-lived tunicate communities and to which toxic coatings cannot be applied.

While the research into the application of the SLIPS technology and design ideas to marine fouling problems are still in its infancy, the range of encouraging results obtained so far show that SLIPS may indeed help to address one of the most pressing economic and ecological problems experienced by modern maritime operations.

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