Battling Biocorrosion in Duluth-Superior Harbor

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University of Minnesota researchers develop novel bioactive coating to protect valuable port infrastructure.

by Annamarie Rutledge

Duluth's $1.5 billion shipping industry has always been vulnerable to shifts in global commodity prices. But the busiest transportation corridor in the Great Lakes also faces a threat much closer to home. Corrosion, accelerated by bacteria in the harbor water, is slowly degrading the 14 miles of port infrastructure that form the backbone of the Duluth-Superior Harbor.

"Biocorrosion is so severe in some places that the steel looks like swiss cheese," said Randall Hicks, a University of Minnesota (Duluth) biology professor, who has studied the problem over the past decade. Biocorrosion in the harbor causes damages at an estimated 50,000 pounds of steel per year, with an expected $350 million replacement cost.

The infrastructure is jeopardized by bacteria in the harbor water that create biofilms, collections of microbial cells that stick to each other and adhere to natural and manmade surfaces. In the harbor, biofilms develop on steel structures, creating a slimy film of composed of algae, diatoms, and bacteria. Once established, bacterial communities form blister-like tubercles on the steel, creating holes that weaken the port infrastructures.

"Controlling biocorrosion in this harbor is difficult. Not only is it very cold in the winter, but there's a lot of ice formation," Hicks said. During the winter, ice scraping up against the steel causes tubercles to open and attract more copper, triggering a peak in corrosion.

Armed with data and better understanding of root causes, Hicks began testing coatings with the potential to inhibit biofilm formation. He had several candidates in mind, when he received a call from Mikael Elias, a Microbiologist at the University's Twin Cities campus who studies bacterial communication. Elias thought the solution to this problem may lie within quorum sensing—a mechanism for bacterial cell communication that is critical for biofilm formation. In fact, the Elias lab had developed a coating that interferes with quorum sensing by using enzymes, molecules that catalyze chemical reactions. "Imagine bacteria have cell phones to communicate and there's a device that scrambles the signal," Elias said. "The bacteria are still there but they can no longer communicate."

Elias'coating prevents microbes from signaling to one another and forming potentially harmful biofilms. "I happened to see an article in BTI's Gateway magazine about Randall Hicks' biocorrosion research and wondered if he would be interested in testing this enzyme," Elias said.

Hicks thought the enzyme could reduce biocorrosion by disrupting microbial communities and preventing attachment. "It turned out that it gave us some of the best results in terms of reducing corrosion tubercles," Hicks said. Elias' molecule outcompeted all other biochemicals Hicks was testing at the time.

MnDRIVE has awarded two grants to Hicks and Elias for their biocorrosion research. "We are really happy to have MnDRIVE funding because we are actually able to test the coating in realistic conditions," Elias said. In field and lab studies, the enzymatic coating has revealed promising results, reducing biocorrosion by 50 percent.

An American team discovered the enzymes used in Elias' coating about two decades ago. Although literature shows these enzymes work well, Elias found no existing technology using them. He realized the molecules were not stable; once used outside the test tube, the molecules lost their activity and benefit. "This is where our lab came in to stabilize them," Elias said.

Elias and his team found enzymes from extreme organisms living in geysers and spring water near volcanoes, which were already quite stable. The Elias lab further stabilized the enzymes by engineering them to increase their thermal stability. The enzymes became resistant to many stressors, beyond expectations.

After this discovery, Elias wondered, "What happens when you dip these enzymes in a coating?" The lab learned that the enzymes were still active and began testing the enzymes in various coatings, from acrylic- to polymer-based. From there, the step to port infrastructure application was small. "We just had to think, where would this be useful? And one place is biocorrosion," Elias said.

Hicks and Elias found that the coating also reduces biofouling—the fouling of underwater structures due to the accumulation of organisms. "Biofouling is a real problem. Not only in the Great Lakes but worldwide," Hicks said. Biofouling causes physical damage, mechanical interference, and ship fuel inefficiency resulting from increased drag. In the United States, biocorrosion and biofouling cost $200 billion in annual maintenance.

The molecule's formulation has been patented, and a two-year study is underway. "The coating we're looking at is environmentally friendly," Hicks said. "The question is whether it's durable enough in harsh field conditions over a longer period of time." If successful, the next step is to license the technology. The Elias lab made the molecule compatible with existing coatings, lowering manufacturing needs.

Biocorrosion has an economic burden on Minnesota transportation and trade, even for cabin owners. Beyond port infrastructure, the coating can be applied to materials such as boats, anchors, and chains, reducing maintenance costs. Hicks and Elias are eager to use their unique molecule to solve local and international biocorrosion and biofouling problems. "This is a technology that has interests beyond Minnesota," Elias said. "It can be applied to many different fields. Essentially anywhere bacteria are a problem."

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