

Novel Anti-Fouling Surface Treatment for Heat Exchangers

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ABSTRACT

Seawater-fed heat exchangers are an effective and cost-efficient method of providing cooling to power plants and refineries located in coastal regions. However, utilization of untreated and unprocessed feedwater comes with its own challenges, including erosion due to sand particle impingement, microbial marine corrosion, and the buildup of biofilms and biofouling limiting the thermal heat transfer. Current methods of mitigating such effects require extensive and costly periodic maintenance, along with significant scheduled exchanger downtime. This work proposes a novel method of addressing these unique challenges through an ultra-low surface roughness treatment that can act as a protective barrier against biofilm formation and erosion, while simultaneously improving the effective heat transfer rate. The treatment contains no biocides or heavy metals, and does not slough off over time like ship hull bottom paints, minimizing its environmental impact, and allowing it to be applied at thicknesses much less than other protective coatings. Unlike traditional coatings, this surface treatment is capable of primer-less application to previously in-service exchangers in-place, allowing it to be evaluated as part of an ongoing maintenance schedule, rather than be only limited to a typical factory-applied pre-installation deployment.

Key words: Power Generation, Coatings, Seawater, Fouling

INTRODUCTION

Utilization of seawater as a heat transfer medium for power plant operations is widespread, owing to the obvious benefit of being a free, unlimited source of a near-constant temperature. Although this single factor vastly outweighs most other economic considerations for other alternative heat transfer fluids, the drawbacks to utilizing seawater must be carefully understood and considered both during the design and long term operation of a heat exchanger system. Chief among an engineer's concerns must be how to control and mitigate the many different types of fouling which can occur on the side of an exchanger directly exposed to the seawater-medium. It is well understood that fouling can cause significant drops in both exchanger efficiency and overall; general estimates are that the economic effects of fouling in highly industrialized nations is roughly equivalent to 0.25% of these nations' GDP¹.

Fouling can take on many different forms based on the ocean chemistry at the given site, the makeup of local marine biomes, water temperature, fluid stream velocity, and particulate concentration (mud and sand). Based on many different case studies presented previously in the literature, it is clear that these factors are not independent, but can in fact have complementary effects greatly increasing the estimated rate of fouling growth; for example, erosion caused by sand impingement may lead to increased rates of corrosion oxide formation, which could then lead to an increased rate of biological organism attachment and colony growth. As such, it is exceedingly difficult to design a universal strategy for fouling control applicable for all types of conditions; mitigation control plans must be designed on a case-by-case basis for each specific site environment².

General design principles for shell-and-tube heat exchangers call for the fluid most likely to exhibit fouling tendencies to always be placed onto the tube side of the exchanger; unless chemical solvents or cleaners are capable of providing adequate cleaning, removal of fouling through direct abrasive washing is normally impossible due to physical access restrictions. Secondly, a fouling factor that can account for expected reductions in heat transfer efficiency must be included when sizing a new exchanger installation; the tubular exchanger manufacturer's association (TEMA) guidelines established and maintained since the 1940s would commonly use a factor of $0.09 \text{ m}^2 \text{ }^\circ\text{C}/\text{kW}$ for seawater used as a cooling fluid under 50°C ³. This means that a typical exchanger would need to be oversized by roughly 33-50% during installation in order to overcome the expected effects of biofilm and corrosion oxide formation. Thirdly, careful considerations must be made as to the types of material used in the exchanger; highly corrosion resistant alloys such as aluminum-bronze and titanium are generally quite expensive as compared to alloys such as stainless steel, 70-30 copper-nickel, or untreated carbon steel combined with cathodic zinc protection. Finally, considerations must be made as to the physical dimensions and specifications of the exchanger; tubes of smaller diameter offer greater cooling capacity per linear foot, however, they are more susceptible to flow disruption and even plugging through narrowing and fouling build up. Exchanger designs with large dead zones where flow velocity is significantly lowered (in the floating head cover between passes, or in the bend of a U-bend exchanger), must also make a significant commitment to periodic maintenance to keep these areas clear⁴.

Despite having these design rules in place, estimating the rate and effect of fouling for any given installation is still far more of an art than a science, and actual manpower availability and downtime schedules will frequently take precedence over strict adherence to the predetermined cleaning and operation protocols for any given exchanger. As such, post-installation strategies to mitigate fouling and improve the performance of already in-service exchangers is highly desired. A common strategy is to modify the surface characteristics and chemistry of the metallic surface itself; by making the surface hydrophobic, both the adhesion strength of biological fouling, as well as the rate of crystallization fouling from mineral deposits can be greatly lowered. Composite coatings utilizing hybrids of sol-gel materials and ceramics⁵, as well as functionalized epoxies and urethanes⁶ have been studied and shown to provide significant reductions in fouling rate, with minimal effects on heat transfer at applied thicknesses below $100 \text{ }\mu\text{m}$. However, these coatings have typically reported challenging application processes, such as long exposure under acidic conditions⁷, electrochemical etching⁸, or curing at temperatures in excess of 100°C ⁹.

This work details the use of a specific type of anti-fouling treatment, trade name HeatX™[†], designed to address this limitation on application; an in-place applicable nano-surface treatment (NST) specifically designed for simple, one-step quick curing at atmospheric conditions on previously in-use substrates with minimal surface preparation required. This NST was a two-part, water-based material specifically designed for maximum wettability onto highly porous substrates such as cement, wood, and glass-flake epoxy, as seen in Figure 1. The NST is designed to cover all exposed surfaces of the substrate, then rapidly cure into a durable, chemically resistant film, capable of preventing water penetration while imparting similar hydrophobicity to other “hydrophobic” coatings. It was expected that the treatment’s ability to closely adhere and protect other porous substrates would enable field application to a severely pitted and worn heat exchanger in-place, significantly shortening the required exchanger downtime and offering an economically attractive option for controlling fouling.

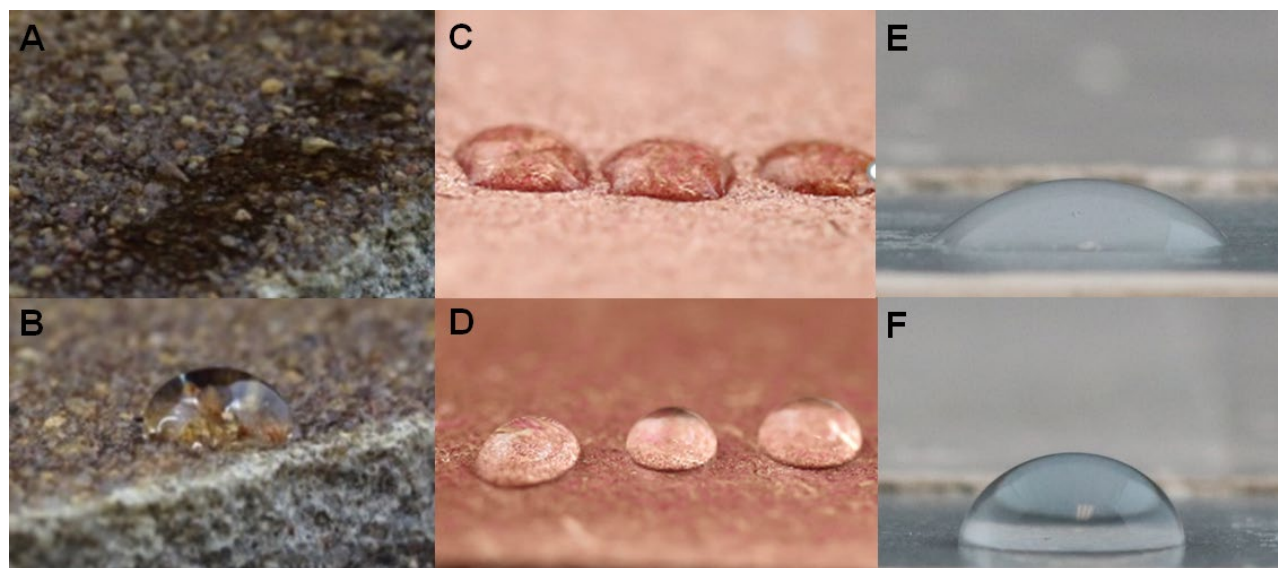


Figure 1 : Application of the NST to various substrates imparts hydrophobicity. Water droplets are shown on previously fouled and cleaned concrete pipeline before (A) and after (B) treatment, a wood panel before (C) and (D) after treatment, and glass flake epoxy before (E) and after (F) treatment.

EXPERIMENTAL PROCEDURE

Treatment Application

The NST was applied to two different test metal substrates specified by different industry partners in the transportation and refining industries. NST application for all substrates called for the substrate to be cleared of all loose dust, dirt, and residual product through water flushing. The NST specifies a NACE 4 cleanliness standard prior to material application, “Brush-off Blast Cleaning, where when viewed without magnification, the surface shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Tightly adherent mill scale, rust, and coating may remain on the surface. Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife”. Material was supplied in a 2-part formulation, where the catalyst is added to the primary polymer solution in a 40:1 w/w ratio, and blended together under constant agitation for a minimum of 15 minutes. During this time, the viscosity of the material increased from approximately 3000 cp to 5000 cp, with a visible color change from a translucent light purple/pink to an opaque white with the consistency of milk. The material was then applied to the laboratory test samples via air-driven spray treatment, applying roughly 15 µm per treatment run with a final minimum applied thickness of 50 µm, with a minimum of 45 minutes allowed to elapse between retreatment to enable a tack-free to the touch finish. Once the specified 50 µm applied thickness was reached, a final 24-hour cure at atmospheric conditions was required prior to any immersion or corrosion testing.