# ESTCP Explores Innovations to Maintain Shipboard Heat Exchangers

## Initial Study Focuses on the Use of Iodine Bubbles to Reduce the Rate of Fouling

**RESULTS OF A** two year project led by personnel from the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) and funded by the Environmental Security Technology Certification Program (ESTCP) assess the potential of use of iodine-laced bubbles to reduce the rate of fouling within Department of Defense (DoD) shipboard heat exchangers.

Shipboard seawater-cooled heat exchangers are installed throughout ships to cool hydraulic, lubricating, and other system fluids, fresh water, or air. Specific applications include providing cooling for engines, air conditioning systems, as well as low and high pressure air systems. Heat exchangers transfer heat generated by a ship's system using either metal tubes or plates to seawater that is discharged to the ocean. Bio-fouling occurs when both non-organic and organic contaminants collect on the surfaces of the tubes or plates in contact with the seawater and a layer forms which reduces water flow and reduces heat transfer.


Air conditioning plant condenser tube sheet from an air conditioning plant on board USS Anchorage (LPD 23).

Bio-fouling can significantly impact the functionality of DoD ships in a number of ways including fouling shipboard heat exchangers and ship hulls. Of particular concern are salt water environments. The existence of barnacles and other marine fouling species greatly increases the foul rate relative to other environments. Fouling of ship's surfaces can result in decreased heat transfer, increased drag, corrosion of ship's materials, increased fuel consumption, and the generation of greenhouse gases.

Seawater bio-fouling occurs by either or both microbial and macrobial fouling. Microbial fouling occurs when microorganisms attract and stick to the heat exchanger tubes. These organisms can be anything from bacteria to slimes and algae. They attach to the heat exchanger wall and form bio-film slimes. Macrobial fouling occurs when larger macro organisms attach to the bio-film rather than directly on to the metal.

### A Challenging Problem

Fouling of DoD shipboard heat exchangers is a chronic and costly operating problem that requires significant maintenance expenditures. Typically, fouling of heat exchange devices is addressed in one of three ways:

1. Take no action.
2. Use acid or mechanical cleaning methods.
3. Use electro-chlorination devices to minimize foul formation.

Each of these methods negatively impacts ship's operating costs, mission readiness, energy use, and the environment. Of particular environmental concern are acid cleaning and electro-chlorination.

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During an ESTCP research project (no. WP-201219) spearheaded by NAVFAC EXWC personnel, investigators found that the liquid waste from acid cleaning had a concentration of 2,000 parts per million (ppm) of copper, 800 ppm of nickel, and 100 ppm of zinc. This waste also had a pH of less than one. Depending on the size of the heat exchangers, these types of cleanings can result in the generation of thousands of gallons of hazardous liquid waste that is regulated by the Resource Conservation and Recovery Act (RCRA). Disposal of this waste normally costs from $2 to $12 per gallon, thus the total cost for a heat exchanger cleaning can easily exceed $100,000. In addition, the acid dissolves ship's materials potentially reducing the system's service life.

On a few DoD vessels, electro-chlorination is used to retard fouling. Use of the technology results in free chlorine release into the ocean. Free chlorine, a halogen, may present a problem in that it can affect photosynthesis of marine organisms. At present, the Clean Water Act limits chlorine release within 200 nautical miles of shore to between 7.5 and 13 parts per billion (ppb). Proposed standards as part of the Uniform National Discharge Standards may further limit release within 12 nautical miles of the United States shoreline. The current standard chlorine dosing level for Navy ships is 200 ppb for two hours a day as a minimum to control bio-fouling.

### The Basics About ESTCP

**THE ENVIRONMENTAL SECURITY** Technology Certification Program is DoD's environmental technology demonstration and validation program. The program was established in 1995 to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use. ESTCP demonstrations collect cost and performance data to overcome the barriers to employ an innovative technology because of concerns regarding technical or programmatic risk.

The program's goal is to identify and demonstrate the most promising innovative and cost-effective technologies and methods that address DoD's high-priority environmental requirements. Projects conduct formal demonstrations at DoD facilities and sites in operational settings to document and validate improved performance and cost savings. To ensure the demonstrated technologies have a real impact, ESTCP collaborates with end users and regulators throughout the development and execution of each demonstration. Transition challenges are overcome with rigorous and well-documented demonstrations that provide the information needed by all stakeholders for acceptance of the technology.

ESTCP issues an annual solicitation for proposals from the Federal government, academia, and industry and employs a competitive selection process to ensure that ESTCP funds high-quality demonstrations. ESTCP requires each project to develop a formal test and evaluation plan. Demonstration results are subject to rigorous technical reviews to ensure that the conclusions are accurate and well supported by data.

ESTCP is managed by a Director and Deputy Director, five Program Managers, and a Financial Officer. The ESTCP office is co-located with the Strategic Environmental Research and Development Program (SERDP) in Alexandria, Virginia. In this joint program structure, the management staff has insight into the entire range of scientific and technical issues associated with an environmental problem, from basic research questions through implementation. ESTCP relies on the technical skills offered by the participating Services serving on its technical committees to assist in the technical aspects of program development, project selection, program monitoring, and technology transfer.

ESTCP projects are managed within the following five program areas:

1. Energy and Water
2. Environmental Restoration
3. Munitions Response
4. Resource Conservation and Climate Change
5. Weapons Systems and Platforms

For more information, visit the program's web site at www.serdp-estcp.org.

ESTCP

Pier-side sewer connection at NAVSTA Mayport.

## A Different Halogen & Method

To extend the periods in between cleanings, while maintaining optimal functionality and thus improving the elemental and functional impact of fouling heat exchangers, a recent NAVFAC EXWC project sponsored by ESTCP and the Navy Environmental Sustainability Development to Integration (NESDI) program demonstrated the suitability of iodine bubble infusion technology. This technology, a proprietary product of I2 Air Fluid Innovation, Inc., utilizes a low volume of elemental iodine (I2) vapor eluted from iodine coated resin beads in an air stream and delivers that vapor via bubbles to the heat transfer surfaces on the seawater side of shipboard heat exchangers. This technology uses microbial interactions to provide a targeted disinfection without the need for treating the entire water volume. The iodine inactivates the fouling microorganisms and thus helps to prevent both the formation of a bio-film and subsequent macro fouling. Through the infusion of air containing elemental iodine vapor into the heat exchanger, this demonstration has shown that the formation of biological foul can be reduced and the period between physical cleanings extended while maintaining acceptable system parameters.

Elemental iodine is a halogen that acts similar to chlorine in its ability to inactivate fouling microbes but with less environmental impact. When iodine is found in both the ocean water and sea life and when newly introduced, rapidly degrades into already present compounds. The method of introduction, as a vapor filled bubble, can offer additional safety, environmental, effectiveness and economic benefits as well.

### Effectiveness of the Iodine Bubble Infusion Technology

The ESTCP-sponsored demonstration showed that the I2 bubble infusion technology can increase the period between cleanings while maintaining system efficiencies. Additionally, the project showed that infused iodine bubbles as part of an in situ cleaning method, reduces cleaning time, the generation of acidic liquid waste, and heat exchanger maintenance costs. The I2 bubble infusion technology has also undergone proof of concept laboratory testing against microbial challenges in other studies. In a Cornell University study sponsored by the United States Department of Agriculture, it has been shown to reduce microbe concentration levels by seven orders of magnitude within 90 seconds in fluids. Studies at Washington State University have shown the technology to be effective in reducing microbes in turbid water and beneath bio-films.

In 2007, the I2 bubble infusion technology had its first commercial implementation. It was used on a fouled industrial geothermal heat exchanger at Standard Microsystems, an electronics technology manufacturing facility located in Hauppauge, New York. Between 2009 and 2010, several other commercial implementations

### For More Insights

FOR MORE INSIGHTS into the reducing the environmental impact of has been a priority of Navy's afloat environmental program for decades. In recent months, the Navy and the U.S. Environmental Protection Agency (EPA) have made great strides toward implementing new nationwide standards for liquid discharges from Navy ships, read our article "Uniform National Discharge Standards Underway: Navy & EPA Make Progress Toward Final Rules" in the summer 2014 issue of *Currents*. You can browse the *Currents* archives at the Department of the Navy's Energy, Environment and Climate Change web site at http://greenfleet.dodlive.mil/currents-magazine.

were completed including the first salt water application for a site in Bermuda. In all instances, I2 infusion was able to retard the formation of foul within previously rapidly fouling heat exchangers.

## A Logical Approach

Regardless of the existence of shipboard electro-chlorination systems, heat exchangers are periodically taken out of service and cleaned by an expensive mechanical or chemical cleaning method. This work is almost always performed while the ship is in port. The period between cleanings depends on the ship's operating tempo and area of operation. Those ships operating in warm water require more frequent cleaning. The overall goal of this demonstration project was the rehabilitation of an already fouled exchanger and a reduction in foul progression under normal operating conditions.

For the technology to be considered useful, and paramount to the success of this study, the project team determined that four important criteria needed to be met:

1. System safety
2. Ease of use and integration
3. Environmental safety
4. Effectiveness in retarding the progression of bio-fouling

To address these criteria, the project was completed in three phases:

1. Laboratory testing
2. Field testing
3. Shipboard demonstration

## Phase 1: Laboratory Testing

In the first phase, the team verified that the non-metallic and metallic materials commonly used within shipboard heat exchangers were compatible with the chemicals used during the I2 protocols. These laboratory tests also verified that the iodinated bubbles did not increase the erosion rate on heat exchanger materials.

## Phase 2: Field Testing

Field testing was performed at the National Energy Laboratory of Hawaii Authority's (NELHA) facility in Kona, HI to determine foul retardation and metal erosion rates for five common heat exchanger metals using warm Pacific Ocean seawater. Testing was performed both in unlit conditions, emulating the heat exchanger interior, and sunlight conditions fostering the growth of algae. Testing showed that the I2 infusion process was not inhibitory to algae growth. Although initial qualitative indications showed a reduction the formation of fouling (see Figures 1 & 2 below), numerous performance problems prevented the completion of this testing.


FIGURE 1: Bio-fouling in un-infused tube.
*Makai Engineering*

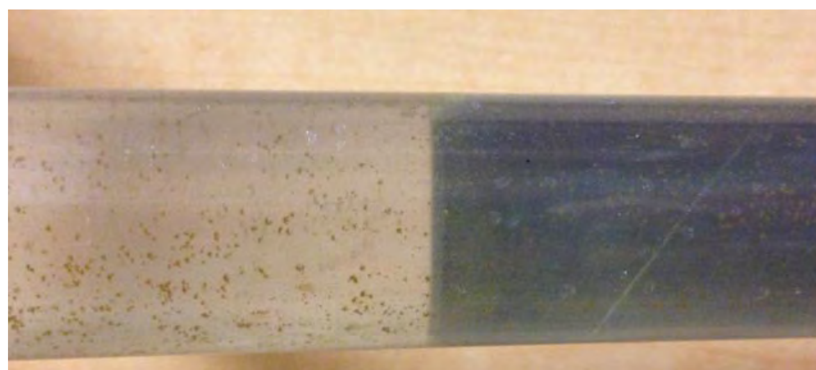
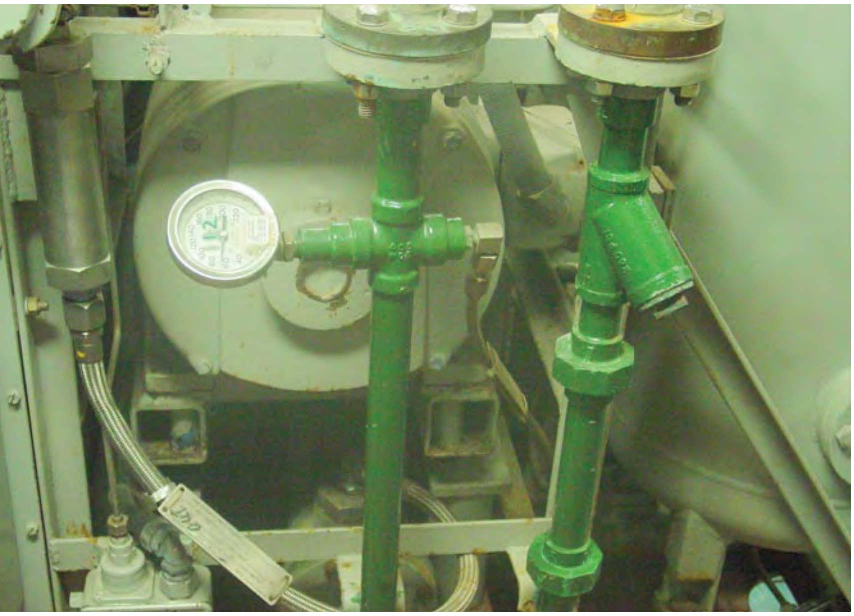


FIGURE 2: Bio-fouling in infused tube.
*Makai Engineering*

## Phase 3: Shipboard Demonstration

Onboard the Self Defense Test Ship (SDTS), homeported in Port Hueneme, California, two identical Low Pressure Air Compressor (LPAC) heat exchangers (numbers 1 and 2), were used for the demonstration. At the start of the demonstration, both exchangers were chemically cleaned using the I2 protocol to establish an identical baseline.

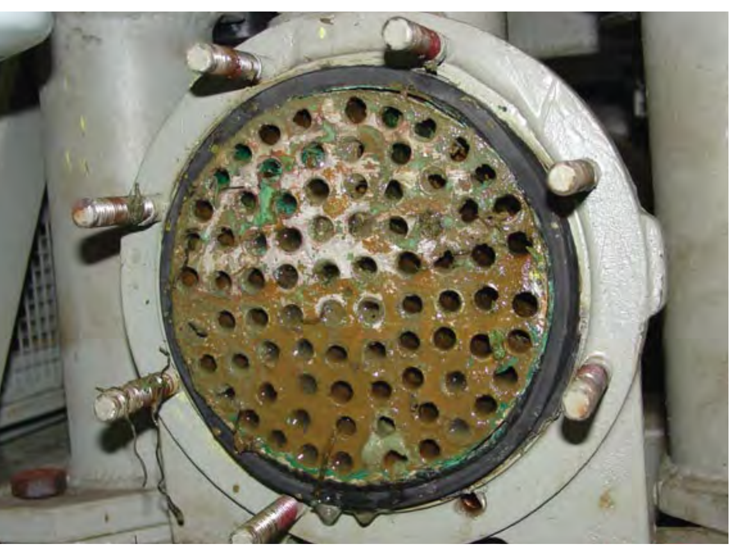
LPAC No. 1 was designated to receive the infusion protocol. The I2 infusion equipment was installed in a



**The number 1 LPAC heat exchanger onboard the SDTS.**
*Bruce Holden*

**The I2 bubble infusion device.**
*Bruce Holden*

small box mounted above the heat exchanger. The demonstration was performed over a period exceeding nine months, with resin cartridges changed approximately monthly. No equipment maintenance was required during the demonstration period. Daily measurements of the inlet and outlet temperatures and inlet pressure readings were recorded on calibrated ship's gauges. These measurements were used to determine the degree of bio-foiling. Periodic water samples were obtained to measure metallurgical elution (dissolved metal content) and sublimation of iodine (in gaseous form). Measuring the amount of metallurgical elution was used to confirm that the protocol did not excessively strip metallic ions from the heat exchanger surfaces which could reduce its service life. Sublimation of iodine measurements served to confirm that iodine discharges would be minimal and given iodine's presence in seawater and marine plant life, present an insignificant ecological risk.



**This photo of the internal heat exchanger tubing in LPAC No. 1 was taken at the conclusion of the demonstration of the I2 bubble technology, shows dirty, but not bio-fouled tubing.**
*Bruce Holden*

Although the project team had wanted each exchanger to be used 50 percent of the time, in actuality, LPAC No. 1 was in use approximately 85 percent of the time. As expressed by the crew, typically this exchanger would have been cleaned every three to six months.

At the end of the demonstration, the temperature and pressure parameters were still within the acceptable range. Water sampling indicated low metal and iodine levels within the effluent. LPAC No. 1 metal ion elution did not vary greatly whether the system was infusing or not. At the end of the demonstration period, the LPAC units were disassembled and viewed for foul progression. The inspection showed that the tubes were relatively clear of solidified foul.

Unfortunately, this project did not result in a definitive and clear indication of success. The fact that the LPAC No. 1 exchanger was used 85 percent of the time meant the control heat exchanger (LPAC No. 2) saw very little use. Ideally, the demonstration would have been continued until such time that the ship needed to perform a heat exchanger cleaning. Since the ship normally cleans the exchangers every three to six months, investigators were, however, able to demonstrate that the I2 bubble infusion technology achieved the project's most important goal—extending the period between cleanings by 50 percent. For additional project results, see ESTCP Final Report TR-NAVFAC-EXWC-EV-1404 posted on the ESTCP web site at www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-201219/WP-201219/(language)/eng-US.


## Ongoing Research

Even with the limited indication of success, two follow-on Navy demonstrations of this technology have been initiated. The technology underwent further study at the Undersea Naval Warfare Center in Newport, Rhode Island as a hull foul retardant in conjunction with air bubble curtains between the spring and fall of 2014. Early observations indicated an inhibitory effect on the growth cycle of some fouling species and on the surface bonding capabilities of barnacles. Water sampling analysis indicated no change in sea water iodine levels during full iodine infusion compared to ambient sea water. Complete demonstration results should be available in the near future.

The technology is also the subject of investigation through the NESDI program. The NESDI program has just launched a project (Bio-fouling Reduction of Ship Cooling Water Systems (project no. 502)) to study the retardation of fouling within a support system heat exchanger used to replace a submarine's heat exchanger while the submarine is undergoing maintenance in a dry dock.

Although not approved at this time, the project team's is working to get the technology demonstrated on a Navy combat ship with the demonstration period long enough to determine how long the I2 technology can extend the period between heat exchanger cleanings. ⚓

### CONTACT

Bruce Holden
Naval Facilities Engineering and Expeditionary Warfare Center
805-982-6050
DSN: 551-6050
bruce.holden@navy.mil

## The Basics About the NESDI Program

**THE NESDI PROGRAM** seeks to provide solutions by demonstrating, validating and integrating innovative technologies, processes, materials, and filling knowledge gaps to minimize operational environmental risks, constraints and costs while ensuring Fleet readiness. The program accomplishes this mission through the evaluation of cost-effective technologies, processes, materials and knowledge that enhance environmental readiness of naval shore activities and ensure they can be integrated into weapons system acquisition programs.

The NESDI program is the Navy's environmental shoreside (6.4) Research, Development, Test and Evaluation program. The program is sponsored by the Chief of Naval Operations Energy and Environmental Readiness Division and managed by the Naval Facilities Engineering Command out of the Naval Facilities Engineering and Expeditionary Warfare Center in Port Hueneme, California. The program is the Navy's complement to the Department of Defense's Environmental Security Technology Certification Program which conducts demonstration and validation of technologies important to the tri-Services, U.S. Environmental Protection Agency and Department of Energy.

For more information, visit the NESDI program web site at www.nesdi.navy.mil or contact Ken Kaempffe, the NESDI Program Manager at 805-982-4893, DSN: 551-4893 or ken.kaempffe@navy.mil.