Proceedings of International Conference on Heat Exchanger Fouling and Cleaning - 2015 (Peer-reviewed)
June 07 - 12, 2015, Enfield (Dublin), Ireland
Editors: M.R. Malayeri, H. Müller-Steinhagen and A.P. Watkinson
Published online
www.heatexchanger-fouling.com

IN-SITU SHIPBOARD HEAT EXCHANGER MAINTENANCE USING INNOVATIVE I_2 BUBBLE INFUSION TECHNOLOGY.

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ABSTRACT

This paper summarizes the results of a two year project led by the Naval Facilities Engineering and Expeditionary Warfare Center to demonstrate the potential for the patented I_2 Vapor Infusion (I_2 VP) system to reduce the rate of foul within Department of Defense shipboard heat exchangers (HX). Fouling of DoD shipboard heat exchangers is a chronic and costly operating problem that requires significant maintenance. The heat transfer performance and efficiency decreases due to the fouling of the heat exchanger plates and tubes resulting in additional fuel consumption and increased greenhouse gases. Costly and labor consuming, remedial chemical cleaning protocols currently used produce considerable hazardous waste (Ye Yi, R. et al, 2002). Laboratory and field testing was used to determine materials interaction and proof of concept prior deployment and study onboard a functioning military test ship. I_2 VP was shown to reduce the formation of biological foul and increase the period between physical cleanings while maintaining acceptable system parameters.

INTRODUCTION

Marine bio-fouling, the accumulation of marine organisms on heat-exchangers used for cooling in a number of shipboard applications, is a challenge in the maritime sector and that has both an economic and environmental impact. Worldwide, the cost of shipboard bio-fouling amounts to tens of billions of dollars each year. Shipboard heat exchangers use seawater as the cooling medium and it contains a rich and diverse source of fouling species. Seawater fouling begins with the attachment of inorganic salts and microbes on heat exchange surfaces which provides an environment for macro fouling species. Fouling reduces the efficiency of the HX which increases ship's fuel use and thus, the generation of greenhouse gases. Bio-films can act as a thermal barrier, degrading heat transfer and the increase in pressure drop is a result of the narrowing of the flow area (Wang et al., 2007). This condition necessitates either onboard periodic chemical cleaning or pier side acid cleaning. If the foul is microbiological in nature, increased corrosion can also lead to significant discharges of heavy metal ions.

Iodine is effective both in air (Raymond, 1946), and water (Chang, S. L. 1958) as a broad spectrum antimicrobial and in iodinated bead form (Ratnesar-Shumate, S., et al, 2008). I_2 VP uses the transfer of elemental iodine vapor off resin beads to an air stream and has been proven to inactivate bio-fouling microbial species through a cell wall/bubble membrane contact. The mass transfer theory for the sublimation of matter from spherical particles is well developed (Bird, R. et al 2002). Land based HX applications have shown I_2 VP to have an inhibitory effect on bio-fouling (Radicone, M. 2013).

The project goal was the rapid rehabilitation of a fouled exchanger and a reduction in foul progression using I_2 VP, under normal operating conditions in comparison to a non infused similar exchanger. Investigated also was that the iodinated bubbles did not increase the erosion rate on heat exchanger materials nor impart significant iodine to the discharged seawater although it is well understood that elemental iodine converts rapidly to iodide and iodate in seawater (Truesdale, V, 1974). During the laboratory phases, we intended to prove that the non-metallic and metallic materials commonly used within shipboard HX were compatible with the chemicals used during the I_2 protocols and proof of concept.

BODY

The Department of Defense (DoD) operates vessels that use heat exchangers (HXs) to cool ship's operating fluids and gases (i.e., water, compressed air, lubricants, etc.). These HXs use seawater as the cooling medium which is prone to cause fouling. To remediate or reduce bio-fouling, three approaches are currently used; no action, chemical/mechanical cleaning, or electro-chlorination. To restore a HX to full performance, it must be cleaned through either mechanical or chemical cleaning or a combination of both. In either case, once water enters the HX, the system begins to foul immediately which is indicated by both an increase in the temperature drop across the HX as well as an increase in HX inlet pressure. Halogens (iodine, bromine and chlorine) have long been used in water purification. Electro-chlorination, currently used by the Navy, is the electrolytic production of sodium hypochlorite from seawater. Unfortunately, recently enacted environmental regulations are challenging the use of chlorination. The patented I_2 VP process is at the core of two methodologies to be tested. The I2CP uses iodinated bubbles in conjunction with mild acid or alkaline cleaners to remove existing foul within a HX. It provides mechanical disruption and cleaner re-distribution. When acid is the cleaner of choice, the solution maintains a lower pH through vapor acidification. This allows for the initial use of milder acid cleaners, and due to bubble perfusion, less volume. The I_2 MP expresses a timed infusion of iodinated air bubbles into the water stream prior the exchanger. This is intended to disrupt the foul progression by inactivating bio-fouling microbes prior bio-film formation and macro species attachment.

This project was completed in three phases; laboratory testing, field testing, and a shipboard demonstration. The primary goal of the shipboard demonstration was the rehabilitation of a fouled exchanger and a reduction in foul progression under normal operating conditions. Phase one laboratory tests determined the effect of I_2 VP on common heat exchanger materials. In the second phase, we preformed field testing as proof of concept at the National Energy Laboratory of Hawaii Authority's (NELHA) facility in Kona, HI. Makai Engineering, a subcontractor to I2 Air Fluid Innovation, designed, installed, and monitored a device to determine foul retardation and metal erosion rates for five common HX metals using warm Pacific Ocean seawater. Testing was performed both in unlit conditions, emulating the HX interior, and sunlight conditions fostering the growth of algae, a key component in the marine food chain. Seawater was run through comparative clear tubes with some receiving infusion and some not. All contained sample of common HX materials.

In phase three, onboard the Self Defense Test Ship (SDTS), two identical Low Pressure Air Compressor (LPAC) heat exchangers (Numbers 1 and 2), were used for the demonstration. Both received the I2CP treatment to form a performance baseline. Prior the study, both HXs were cleaned on the same day, requiring only 3 ½ hours each without the need for disassembly. Waste was collected and measured for volume and sampled for metal content. The time required and the effluent collected met the performance objectives for the I2CP. LPAC No. 1 was designated to receive the infusion protocol, I2MP. The demonstration was performed over a period exceeding nine months, with resin cartridges changed approximately monthly. Measurements of the inlet and outlet temperatures and inlet pressure readings were recorded on calibrated ship's gages. Water samples were periodically obtained to measure metallurgical elution and sublimation of iodine. The project team asked that each exchanger be used 50% of the time.

RESULTS

In the laboratory phase of the project, we verified that the non-metallic and metallic materials commonly used within shipboard HX were compatible with the chemicals used during the I_2 protocols. This was determined through SEM microscopy and metallurgical evaluation which indicated minimal surface disruption of the metals investigated. Gas chromatography, TDS and TSS study was used for metallic and non metallic elution and indicated minimal interaction or loss of material. At the Kona, HI facility preliminary results indicated that I_2 VP did have an inhibitory affect on foul progression as indicated by Figure 1 showing two tubes after 45 days of flow with one tube receiving iodinated infusion and the other not. Sunlit tubes indicated that the I_2 infusion process was not detrimental to algae growth. Although initial qualitative indications showed a reduction in foul formation, numerous performance problems by Makai Engineering resulted in the project team not achieving the intended goals as specified in the Demonstration Plan.

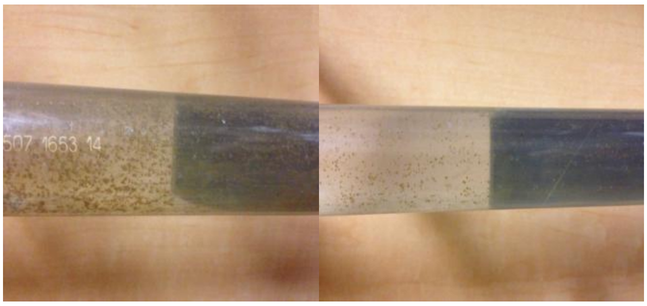

Figure 1: Comparative tubes 45 day
Left image un-infused, Right infused

On board the test ship and during the study period, measurements of temperature and pressure were taken every half hour on both exchangers by the crew. The measurements for LPAC #1were charted as shown by the chart in Figure 2. Also displayed by the chart is individual HX in use period, where the darker grey is the infused LPAC No.1 and the lighter grey the un-infused LPAC no.2 and black is system shutdown. The yellow lines indicated an acid clean of the exchanger. The data indicates the following;

1. During the study period the operating parameters of infused LPAC No. 1 exchanger remained in normal range without the need for maintenance.
2. LPAC No. 1 was in use approximately 85% of the time instead of the requested 50/50 duty cycle.
3. As expressed by the crew typically both exchangers would have been cleaned every 3 to 6 months but during this demo neither required cleaning.
4. After a nine month period under excessive use, the temperature and pressure parameters of LPAC No. 1 were the same before and after an acid cleaning as indicated by the blue box.

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 and prior the acid cleaning, the LPAC face plates were removed and viewed for foul progression. The inspection showed that the tubes were relatively clear of solidified foul. The units were re-assembled and had an I_2CP performed using an acidic cleaner. The effluent from each was analyzed for Total

Suspended Solids (TSS), Total Organic Carbon (TOC) and Total Dissolved Solids (TDS) as well has Ti, Cu, Ni, Zn and Pb content before and after the cleaning. The cleaning solutions for both HXs indicated less metal elution than with normally used Navy cleaning procedures.

The fact that the LPAC No. 1 exchanger was used 85% of the time meant the control HX, LPAC No.2, saw very little use. Ideally, the demonstration would have been continued until such time that the ship needed to perform a HX cleaning. Since the ship normally cleans the exchangers every three to six months, we were, however, able to show use that I_2 VP did achieve our most important goal of extending the period between cleanings by 50%.

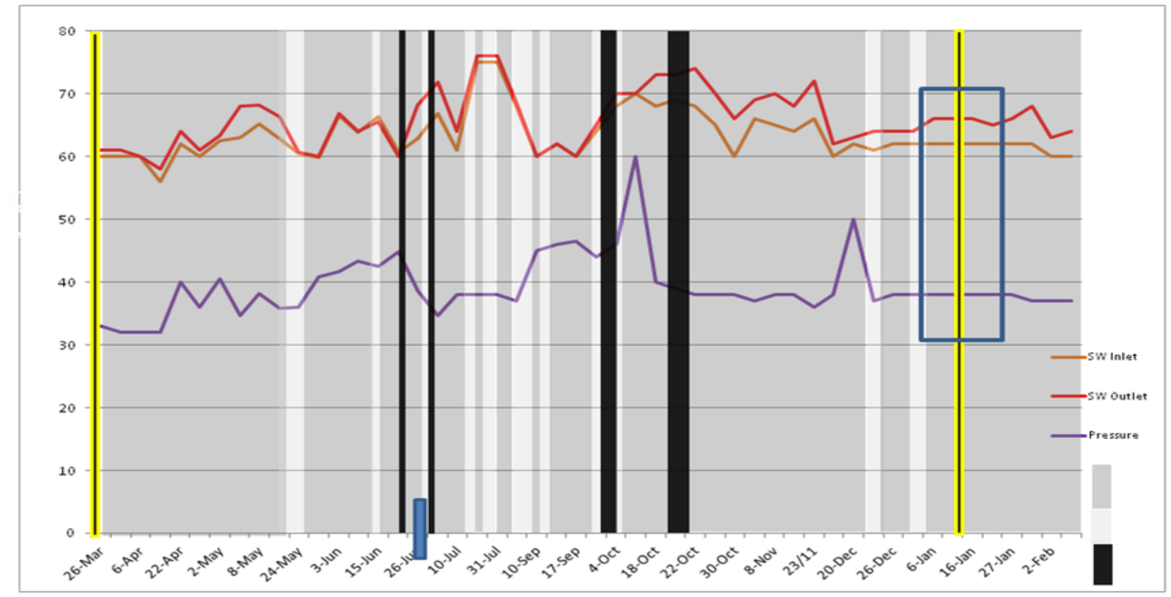

Figure 2: Pressure and temperature chart LPAC # 1

DISCUSSION

Although we were able to acheive our primary goal of extending the time period between cleanings onboard the SDTS, engineering failures at the Hawaii site prevented gathering considerable visual data. Of significance though was that the I_2 VP protocol required no crew interaction other than a 5 minute monthly cartridge change during the 9 month test period and that all effluent water samples indicated no significant elution of metals or a rise in background iodine. The protocol used approximately 6-9 grams of iodine per month as indicated by cartrdige weight loss. The correlation between reduced fouling and minimal iodine residue is important in the face of concerns over biocide discharges.

CONCLUSION

Extending the time period between HX cleanings can offer significant benefits to the DoD which could transition to all maritime entities both governmental and commercial. Even with the limited indication of success, two follow on Navy demonstrations of this technology have been initiated. One as a hull foul retardant and the other to prevent bio-fouling in a submarine salt water heat exchange support system.

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