Environmental effects of heat exchanger fouling and reducing fouling with **vapor infusion technologies**

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Michael Radicone
Lead, Specialty Products

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Environmental impact of heat exchanger fouling and mitigation protocols

These fouling-related conditions will impair heat exchanger functionality and increase generation of greenhouse gases

- Surface insulation of fouling layers
- Under-deposit corrosion by chemical or biological agents
- Increased pressure drop due to flow impeded by fouling
- Maldistribution of flow away from heat transfer surfaces
- Formation and subsequent discharge of deposits, biofilms, or disinfection/anticorrosive byproducts into environment and internal components
- Hazardous cleaning chemical generation, handling, and disposal

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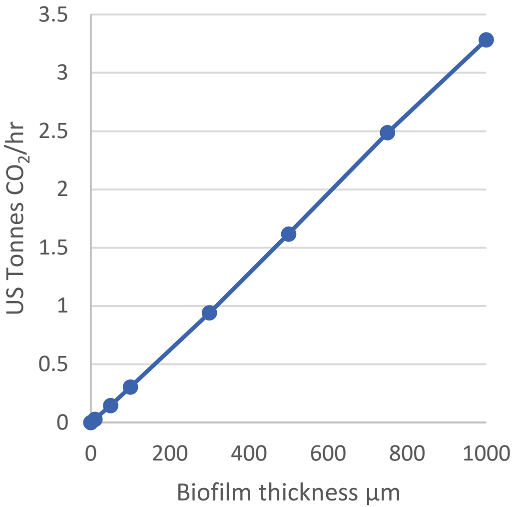
The environmental effect of heat exchanger fouling: A case study

T. Casanueva-Robles and T. R. Bott

Proc. 6th Intl. Conf. Heat Exchanger Fouling and Cleaning – Challenges and Opportunities, ECI Symposium Series (2005)

Additional CO_2 produced by increasing biofilm thickness
(Assuming thermal conductivity of biofilm = static water)



Conclusions from case study:

- "…the presence of unwanted deposits on heat transfer surfaces in power station steam condensers can increase the discharge of 'greenhouse' gases. The extent of the increase is of course dependent upon the thickness of the deposit."
- The loss of heat recovery and the additional energy for pumping represent a loss of thermal efficiency. When fuel combustion supplies energy, additional greenhouse gas emission will result.

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Heat exchanger fouling: Environmental impacts

Editorial

H. Müller-Steinhagen, M. R. Malayeri, and A. P. Watkinson

Heat Transfer Engineering **30**(10–11), 773 – 776 (2009)

- CO_2 emissions from additional primary fuel burned to compensate for heat exchanger fouling and inefficiencies
- Health issues related to NOx and SOx emissions from scrubber heat exchangers
- Restrictions on disposal of chemical wastes
  - ✓ Chemical cleaning discharges
  - ✓ Disinfection byproducts
  - ✓ Hazardous health damaging waste to environmental pathway such as bacteria and fungi, carcinogenic matter
- Limitations in cooling water use due to effluents and temperature

Vapor infusion is the environmentally safer alternative

- Maintains optimum heat exchanger functionality longer, reducing energy needs
- Does not allow heat exchanger to achieve critical fouling condition
- Reduces treatment chemical expression through timed expression
- Reduces greenhouse gas generation through higher operating efficiencies
- Minimizes fluid-borne chemical residues
- Provides turbulence and impact treatments, preventing foul buildup
- Maintains fluid pathways to reduce pump output
- Reduces or eliminates need for hazardous chemical or mechanical treatments
- Extends times between cleaning
- Reduces or eliminates hazardous cleaning chemical generation
- Reduces unintentional fluid discharges such as biological enzymes, disinfection byproducts, biofilms, or metal ions

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Studies indicate numerous benefits of bubbles within heat exchangers

Enhancement of heat transfer due to bubbles passing through a narrow vertical rectangular channel
Monde, Mihara, Mitsutake, and Shinohara
Wärme-und Stoffüfbertrangung (1989)

Thermal performance improvement by injecting air into water flow
Chang and Huang
J. Heat and Mass Transfer (2013)

Heat transfer enhancement due to air bubble injection into a horizontal double pipe heat exchanger
Dizaji
Intl. J. Automotive Engineering (2014)

Decreasing the scale fouling of heat exchanger plates using air bubbles
Baek, Seol, Lee, and Yoon
Defect and Diffusion Forum (2010)

Heat transfer enhancement caused by sliding bubbles
Bayazit, Hollingsworth, and Witte
J. Heat Transfer (2003)

> "Vapor and gas bubbles are known to increase heat transfer rates from adjacent heated surfaces, a phenomenon attributed to the interaction between the bubble and the thermal boundary layer."

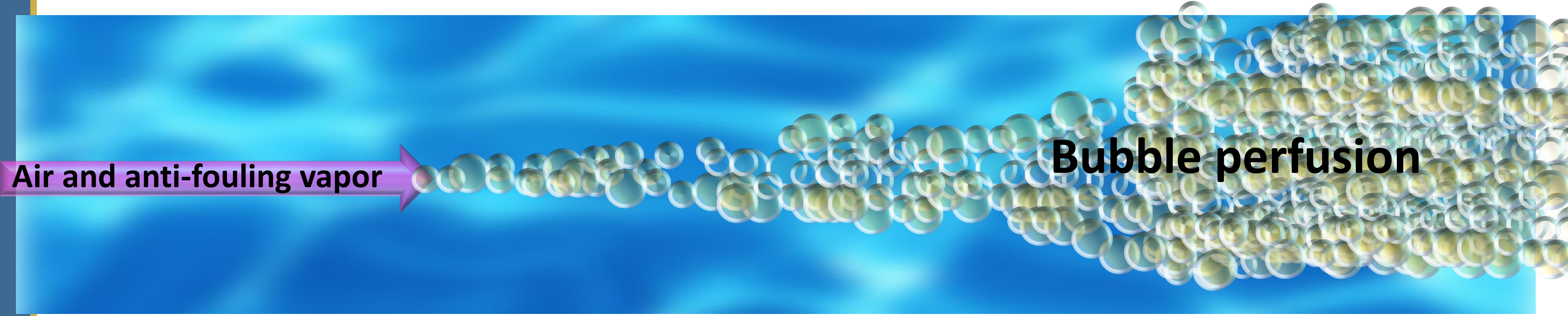
Dynamic flow structures in the wakes of sliding bubbles for convective heat transfer enhancement
Meehan, Donnelly, Persoons, and Murray
Intl. Heat Transfer Conference (2014)

Effects of bubble size on heat transfer enhancement by sub-millimeter bubbles for laminar natural convection along a vertical plate
Kitagawa, Uchida, and Hagiwara
Intl. J. Heat and Fluid Flow (2009)

Unfortunately, aeration only of cooling water can introduce ***dissolved oxygen*** through mass transfer ***inducing corrosion or accelerated biofouling***

Bubble vapor treatment (BVT)

Vapor infusion is patented process that safely generates SCRUBBING, transitory bubbles to reduce formation of foulants on heat exchanger surfaces while imparting targeted and reduced chemical treatments



Bubbles have low oxygen and chemical treatment vapor core and aqueous reactive surface that

- present reduced treatment volume
- inhibit corrosion
- mechanically disrupt fouling formation
- reduce sedimentary action
- works during process operation unlike cleaning in place (CIP), teardown, and sponge ball cleaning protocols

Vapor infusion technology

- uses pulsed air proportioned with working fluid
- is adaptable to most environments
- requires grams per application

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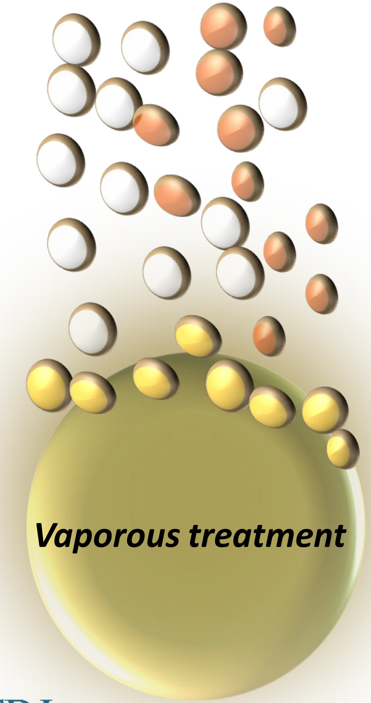
BVT provides dynamic bubble with reduced oxygen*

*compared to ambient aeration

Micro fouling agents
(scaling, biofouling, barnacles, ect.)
Macro fouling agents
(minerals, mud, metals, etc.)
from process equipment water



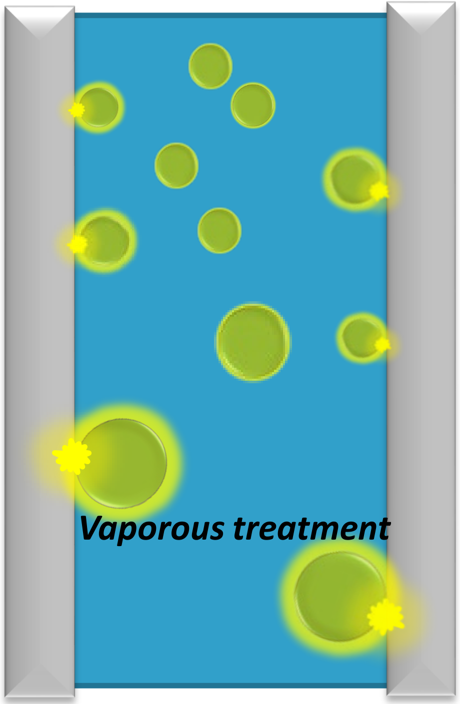
Bubble impact through induced turbidity, vapor density, and molecular mass

Bubble surface vapor transfer provides both gaseous and aqueous presentation of treatment chemical through bubble surface

Gas solubility provides presentation of chemical treatment into fluid surrounding bubble

Little change in pH in treated water

Micro fouling agents
(scaling, biofouling, barnacles, ect.)
Macro fouling agents
(minerals, mud, metals, etc.)
<u>on process equipment surfaces</u>



Laboratory research at Washington State University and Cornell University demonstrates effectiveness of bubble surface vapor transfer

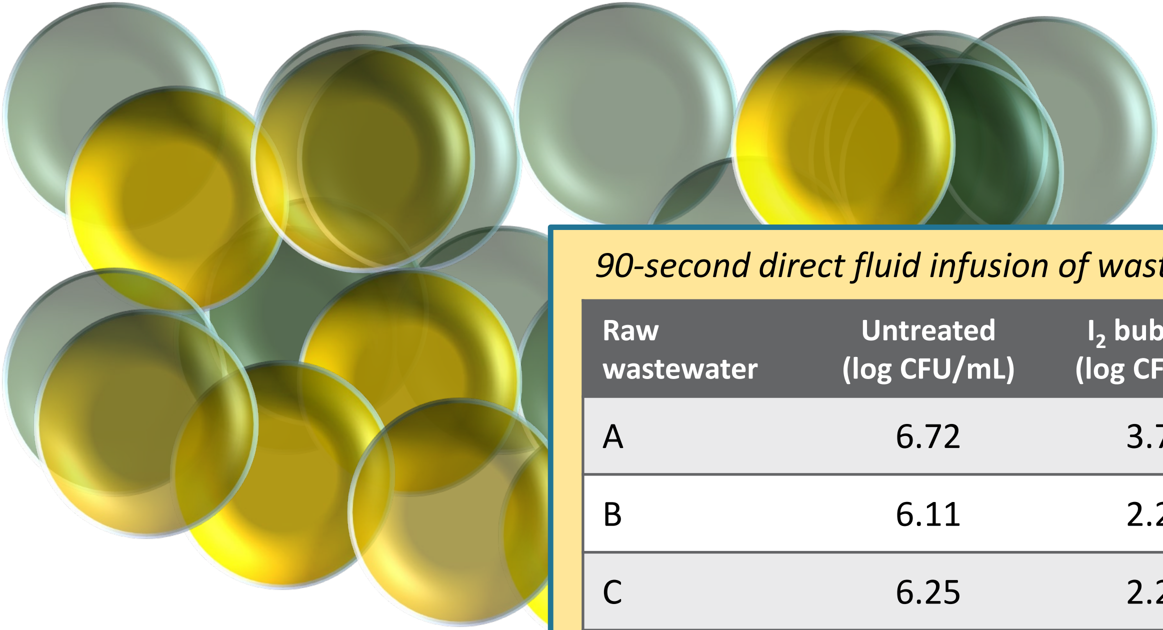
- Using only vapor transferred through bubble membrane, these studies indicated iodine biocide transfer was highly effective and produced minimal residue
- One 90-second infusion resulted in **< 50 ppb residue in fluid volume**

Bacteria	Initial concentration (log CFU/mL)	Final concentration (log CFU/mL)
E. Coli K12	6.12	undetected
E. Coli 0157:H7	6.48	undetected
Salmonella	6.28	undetected
Enterococcus	6.56	undetected

CFU – Colony forming units

(Vapor infusion using iodine is not for import, distribution, sale or use in the United States of America.)

Bubble <u>segregates</u> treatment-vapor from fluid volume; organic matter, turbidity and temperature have less affect on treatment-vapor and as a result will form less byproduct.



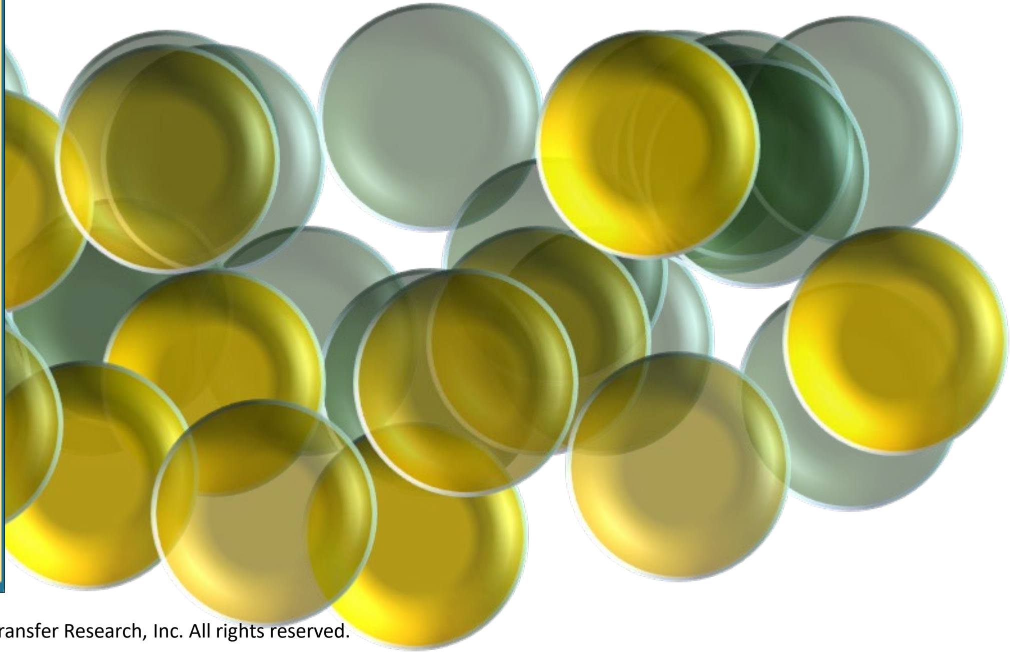
90-second direct fluid infusion of wastewater (Washington State University)

Raw wastewater	Untreated (log CFU/mL)	I_2 bubbling (log CFU/ml)	Log change	Average change
A	6.72	3.71	-3.02	
B	6.11	2.26	-3.85	-3.62
C	6.25	2.26	-3.99	

Air treatment vs iodine vapor infusion

	Water sample	Treatment time (seconds)	Log of CFU/mL
	A	n/a	7.05
	B	n/a	7.09
	C	n/a	7.35
Air only treatment			
	A	90	6.7
	B	90	7.24
	C	90	7.24
Air only treatment			
	A	180	7.12
	B	180	7.12
	C	180	6.93
Iodine vapor infusion treatment			
	A	90	undetected
	B	90	undetected
	C	90	undetected
Iodine vapor infusion treatment			
	A	180	undetected
	B	180	undetected
	C	180	undetected

Iodine vapor penetrated the mature biofilm killing the bacteria within it.



ESTCP study compared two similar shell-and-tube heat exchangers, one infused and one used as control, onboard a working Navy test ship
Result: No release of metal or non metallic ions during infusion and a complete inhibition of biofouling in infused unit

Success criteria	Actual outcome
A 50% increase between acid cleanings from 60 days to 90 days.	270 days* end of study.
Less than 200 ppb increase in iodine in effluent.	Only 35 ppb increase.
Low increase in metallic ions during infusion.	No increase.

No difference in temperature and pressure before and after a final acid wash, indicating zero biofouling*

***Reduction in cleaning time by 50% and hazardous waste generated*

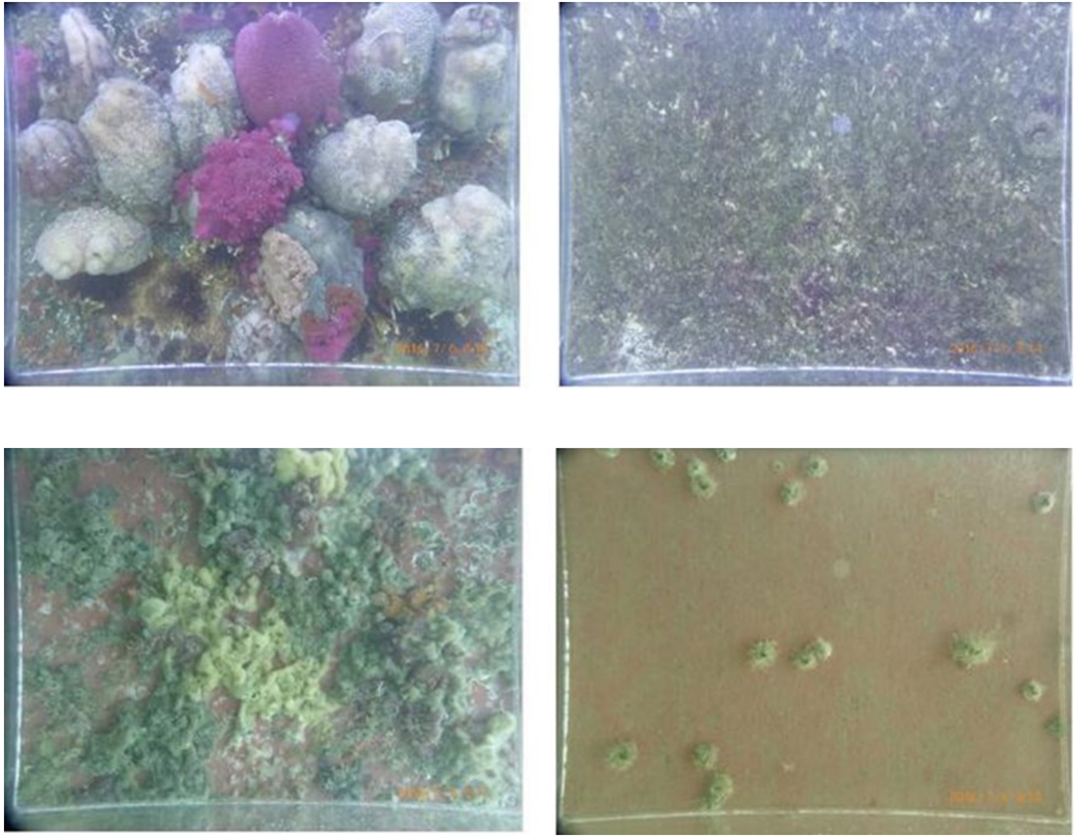
- Infusion duration was only 3 minutes per half hour, and total monthly cartridge iodine loss was less than 20 grams
- The infused exchanger was used 85% of time and still exhibited no biofouling

Ship hull hard foul prevention

Three-year laboratory study at the Naval Undersea Warfare Center Division and Florida Institute of Technology for prevention of hard foul on ship hull

Results from hull simulation fiberglass plates.

Controls | **Iodine vapor treated**



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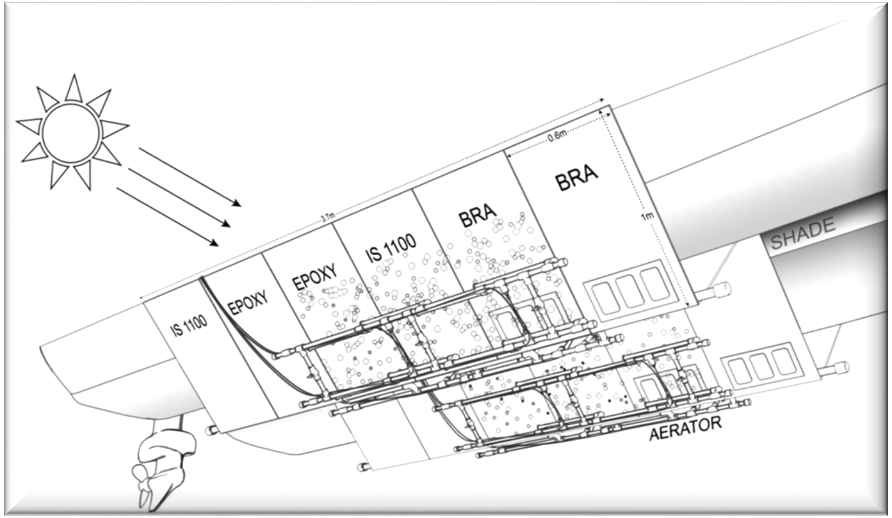
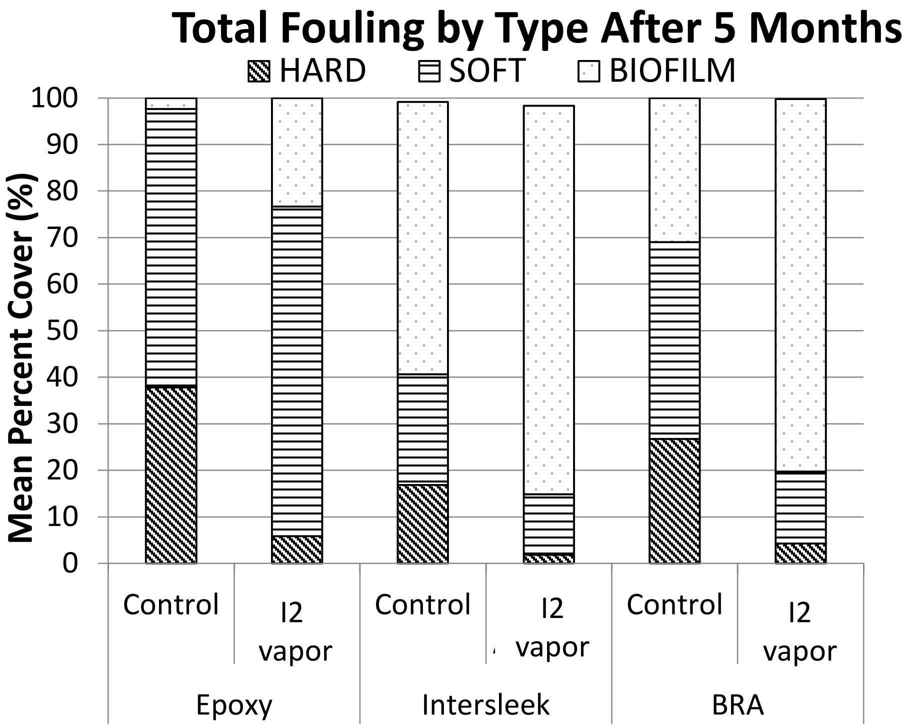
Ship hull hard foul prevention on antifouling paint surfaces; iodinated air and control

Undersea Warfare/Newport, RI and Florida Inst. Of Technology/Coco Beach, Florida





"Early observations indicate an inhibitory effect on the growth cycle of some fouling species and on 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."

Vaporous treatments

Iodine*

- Biofouling
- All surface treatment
- Microbial inhibition
- Macro foul disruption
- Void and containment disinfection

Bubble Characteristics

Iodine vapor core

Continual iodine biocidal source

Iodine aqueous surface

Microbial inhibition, Macro foul disruption, Void and containment disinfection

Reduced oxygen presentation

Reduced foul support

Marginally soluble in water

Low fluid residue

Denser than air

Disruptive bubble, greater impact

Bubble Characteristics

Benzotriazole vapor core

Continual vapor corrosion inhibitor (VCI) source, oxygen scavenging, ^{-}OH and H^{+} compatible, pH neutral

Benzotriazole aqueous surface

VCI/foulant contact

Reduced oxygen presentation

Reduced corrosion and foul substrate support

Marginally soluble in water

Low fluid residue

Denser than air

Greater impact of disruptive bubble

Benzotriazole

- Scaling and corrosion inhibitor
- All metal treatment
- Ferrous and cupreous corrosion inhibition
- Macro foul disruption
- Void and containment corrosion inhibition

Benzoate salts

- Ferrous metal treatment
- Ferrous corrosion inhibition
- Macro foul disruption
- Void and containment corrosion inhibition

Bubble Characteristics

Benzoate vapor core

Continual vapor corrosion inhibitor (VCI) source, oxygen scavenging

Benzoate aqueous surface

VCI/foulant contact

Reduced oxygen presentation

Reduced corrosion and foul substrate support

Marginally soluble in water

Low fluid residue

Disruptive bubble

**NOTE: Iodine is not for sale or use in the United States of America*

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Cruise and cargo ships

Norwegian Cruise Lines®

Engine coolers on Norwegian Sun

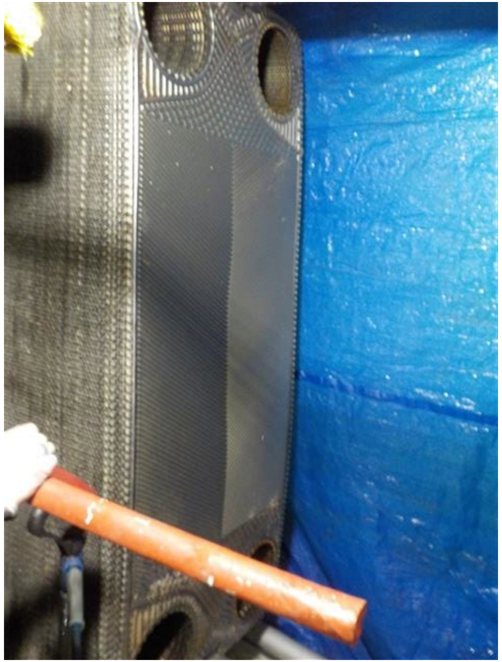
Both sets of main engine coolers (2), forward and aft, had been in operation without being cleaned for over a year. Fourteen months after installation of the vapor infusion system (**after 26 months in operation**), each exchanger was opened for observation.

from First Engineer, Norwegian Sun:

"Michael,

All 4 LT coolers were found in good condition after a few years in operation.

Thanks"



Aft engine cooler
No biological or mineral fouling

Images used with permission of Norwegian Cruise Lines®

Forward engine cooler
No biological or mineral fouling

Drilling ships and offshore rigs

Semi-submersible offshore drilling ship installation

- Thruster engine coolers-(8); 3800 kW each
- Main engine coolers-(8); 5060 kW each
- Miscellaneous exchangers-(4)
- Vapor infusion systems to service all exchangers-(10)

From the engineer:

Infusion system was installed on thruster #6, a cooling plate heat exchanger, **constantly operating for three months**. During pressure drop tests with high loads (including 100% load tests for 15 minutes), thruster #6 **performed better** than other thrusters that had been opened and cleaned a few months before the tests.

From the engineer:

During this trial, the ship was anchored near shore, with red dust in the water and over the vessel. The load tests in the pressure drop trials stirred up marine/sea bed into all of the sea water strainers. When Thruster #6 was opened, the buildup was a mud, with no hard scale or marine growth that wiped clean with ease.

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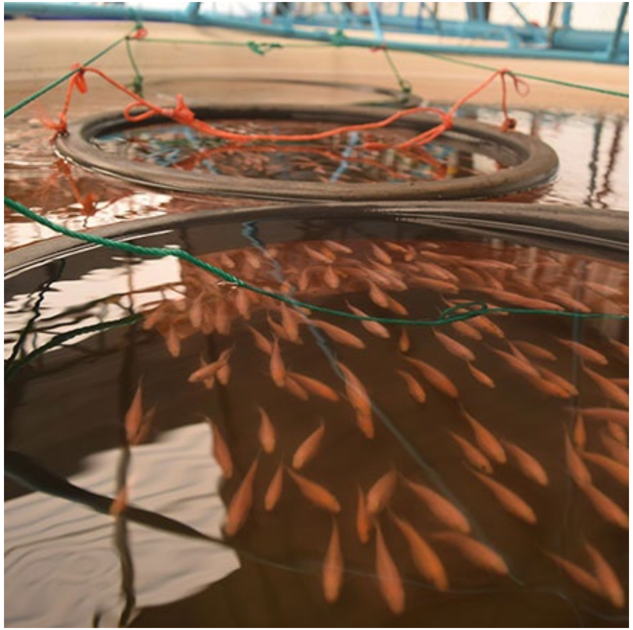
Aquaculture systems

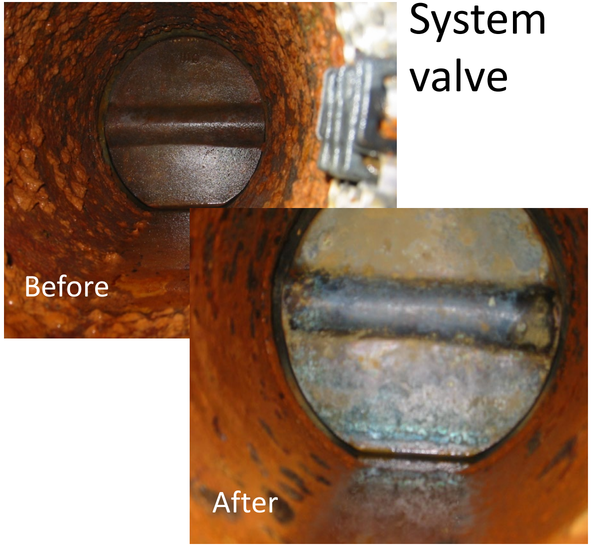
- Hatcheries
- Lobster farms
- Fish farms - halibut, salmon
- Elimination of chlorination
- Reduction in heat exchanger tear down, cleaning and reassembly

A commercial halibut hatchery uses plate heat exchangers to control the water temperature of its fish tanks. To reduce fouling in the tanks, the aquaculture farm had been back-flushing the tanks weekly and using hypo-chlorination twice a week. Our vapor infusion system was installed as an alternative. After three months, the company had substantially reduced maintenance and operating costs.



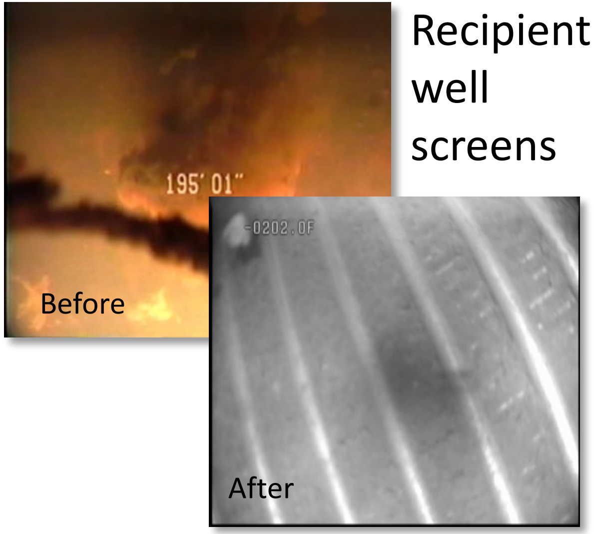
Geothermal

A geothermal system at Microchip Technology, Inc.'s, formerly Standard Micro Systems Corporation, electronic manufacturing facility was experiencing severe fouling. The design pressure of the heat exchanger was 6 psi. Iron-reducing bacteria fouling caused an inlet back pressure of 30 psi and greater, as well as rapid recipient well back pressure.



System valve

Heat exchanger plate



Recipient well screens

Since installing the vapor infusion system the facility has not had to chemically or mechanically clean the heat exchanger. As an added benefit, the residual microbubbles of antifoulant vapor have also kept the downstream recipient well screens clean.

Processing Plants

Vapor infusion implementation on shell-and-tube heat exchangers

Sulfuric acid plant using seawater as coolant experienced **zero increase in seawater iodine level** in system effluent.

Improved heat exchanger operation

- Stabilized temperature spikes
- Experienced a 6 ºF reduction in process fluid temperature

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Simple integration, operation and low cost

System to provide treated air to scrubber and cooling water-side of heat exchanger requires

- **location** - with ambient temperature between 65 and 95 °F
- **mounting surface -** capable of supporting 50 pounds
- **air source** - dry (entrained water removed), oil free, regulated at a flowrate capable of producing the needed volume of air and pressure greater than the maximum operating pressure of the working fluid.
- **electric source -** within 10 ft. of the vapor infusion system control device
  (12-, 24-, 110-, and 220- volt systems available)
- **pipe connection -** ½-in. NPT female pipe connection 2 – 4 ft. from heat exchanger water inlet

Vapor infusion device

Infusion wand assembly

Red Tubing, from air source to device inlet
White tubing, air & vapor to infusion wand then heat exchanger

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Mike Radicone

mike.radicone@htri.net

1.979.690.5050

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