



The Science, Creation and Environmental Impact of Vapor Infusion Nano Bubbles

<https://www.htri.net/vapor-infusion>

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Environmental impact of heat exchanger fouling

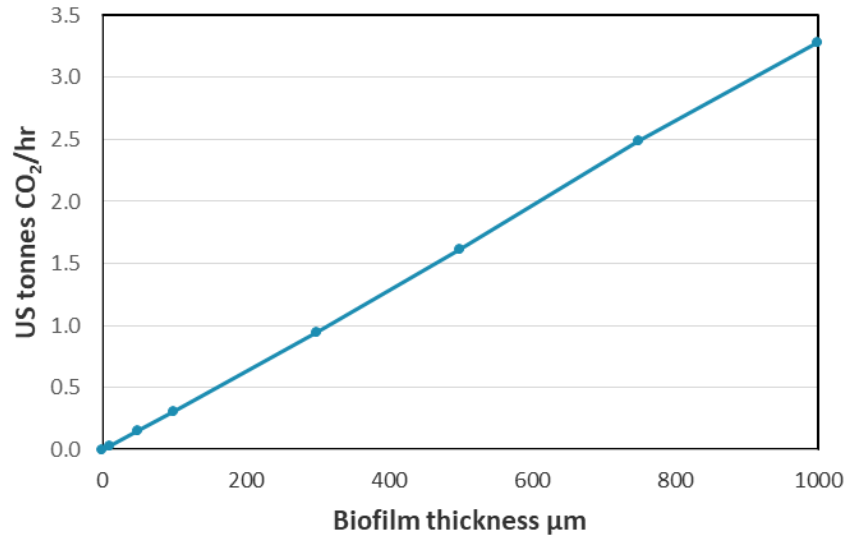
Fouling related conditions impair heat exchanger functionality and increase generation of greenhouse gases

- Surface insulation of fouling layers
- Increased pressure drop due to flow impeded by fouling
- Maldistribution of flow away from heat transfer surfaces

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)

Increasing biofilm thickness produces additional CO₂
(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.

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)



CO₂ emissions from additional primary fuel burned to compensate for heat exchanger fouling and inefficiencies



Health issues related to NO_x and SO_x emissions from scrubber heat exchangers



Restrictions on disposal of chemical wastes



Limitations in cooling water use due to effluents and temperature

Studies indicate numerous benefits of bubbles within heat exchangers

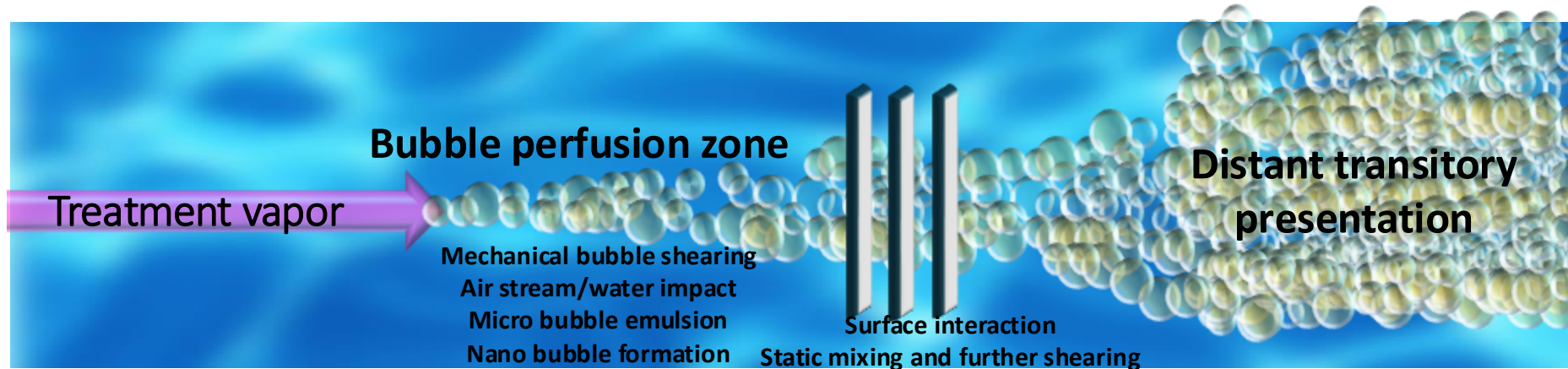
- Enhancement of heat transfer due to bubbles passing through a narrow vertical rectangular channel
- Thermal performance improvement by injecting air into water flow
- Heat transfer enhancement due to air bubble injection into a horizontal double pipe heat exchanger
- Decreasing the scale fouling of heat exchanger plates using air bubbles
- Heat transfer enhancement caused by sliding bubbles
- Heat transfer augmentation: Experimental study with nanobubbles technology
- Dynamic flow structures in the wakes of sliding bubbles for convective heat transfer enhancement
- Effects of bubble size on heat transfer enhancement by sub-millimeter bubbles for laminar natural convection along a vertical plate

Unfortunately, aeration using ambient air can introduce ***dissolved oxygen*** through mass transfer ***inducing corrosion or accelerated biofouling***

Vapor bubble infusion

Vapor bubble infusion (VBI) is a patented process that safely generates a timed presentation of SCRUBBING, transitory multi-sized bubbles to **retard** the formation of foulants on heat exchanger surfaces while imparting targeted **but** reduced chemical treatments.

Timed infusion works in harmony with most anti-fouling systems.



- presents a reduced treatment volume
- inhibits corrosion
- mechanically disrupts foul formation
- reduces sedimentary action
- works during function, unlike CIP, teardown, and sponge ball cleaning protocols

- Pulsed, air/fluid proportioning (no disruption to water flow)
- Adaptable to any environment
- **Only grams per application**
- **Extremely low fluid residual**

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

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

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

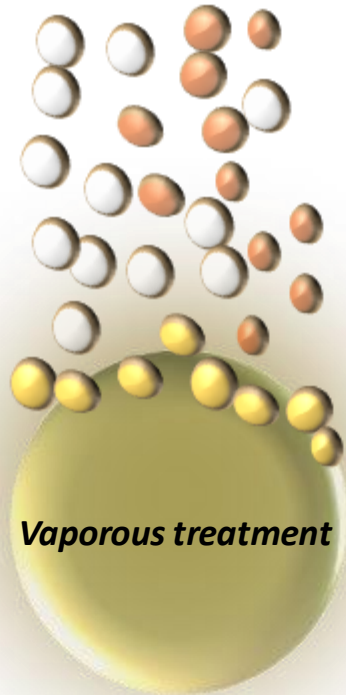
Low fluid residue

Disruptive bubble

VBI provides dynamic bubbles with reduced oxygen*

*compared to ambient aeration

*Treats free floating
micro and macro fouling agents
(Biological, mineral, sediment, metals, etc.)
from process equipment water.*



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

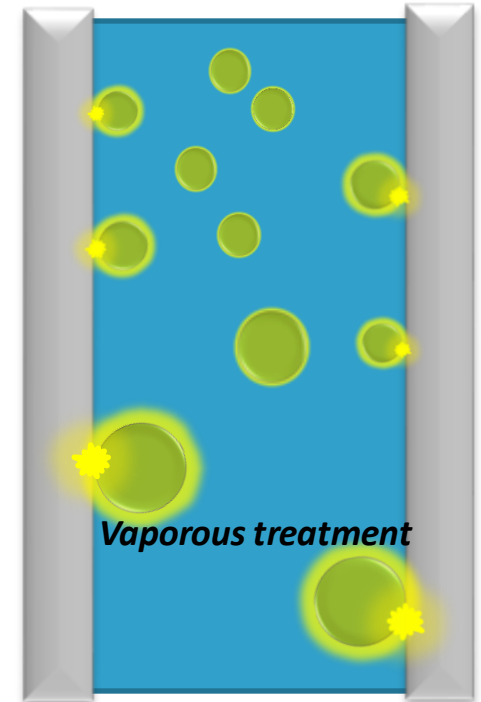
Bubble surface vapor transfer provides both gaseous and aqueous presentation of treatment chemical through bubble surface

Gas solubility provides presentation of chemical treatment into fluid surrounding bubble with minimal rise in DO.

Little change in pH and DO in treated water

Foul penetration through nano bubbles

*Treats surface formation of
micro and macro fouling agents
(Mineral, biological, sediment, metals, etc.)
from process equipment surfaces.*



University studies demonstrate vapor infusion conveys treatment through a bubble/contaminant interaction.

Results of one 90-second infusion High log reduction

Bacteria	Concentration, Log CFU/mL	
	Initial	Final
<i>E. Coli</i> K12	6.12	0.00
<i>E. Coli</i> 0157:H7	6.48	0.00
<i>Salmonella</i>	6.28	0.00
<i>Enterococcus</i>	6.56	0.00

Results of one 90-second infusion Biofilm (MRSA) inactivation

Biofilm treatment	Time, s	Log CFU/mL
None, A	—	7.05
None, B	—	7.09
None, C	—	7.35
Air, A	90	5.25
Air, B	90	5.63
Air, C	90	5.37
Iodine, A	90	0.00
Iodine, B	90	0.00
Iodine, C	90	0.00

Results of one 90-second infusion Residual inactivation-nano bubble

Sealed container	
Time, hr	CFU/mL
0	0
1	20
2	480
4	5250
6	tntc

After 90-second infusion, the fluid volume held **less than 50 ppb residue**, indicating nano bubble presentation

The “magic carpet” of Vapor Infusion, Nano Bubbles



Nano bubbles can impact the solubility of mineral masses.

A. Li, Y. Li, S. Qiu, P. M. Patel, Z. Chen and J. C. Earthman, “Reduction of Calcified Plaque Volume in Ex Vivo Pericardial Tissue, with Nanobubbles,” *Colloids and Surfaces B: Biointerfaces*, 217, 112666 (2022).



Nano bubbles are created through microbubble shrinkage.

P. A. Satpute and J. C. Earthman, “Hydroxyl Ion Stabilization of Bulk Nanobubbles Resulting from Microbubble Shrinkage,” *Journal of Colloid and Interface Science*, 584, 449-455 (2021).



Nano bubbles can impact the solubility of calcium carbonate.

Vu-Y Quach, A. Li, and J. C. Earthman, “Interaction of Calcium Carbonate with Nanobubbles Produced in an Alternating Magnetic Field,” *ACS Applied Materials & Interfaces*, 12, 43714-43719 (2020).



Impact of gas ultrafine bubbles on the efficacy of antimicrobials for eliminating fresh and aged *Listeria monocytogenes* biofilms on dairy processing surfaces

Phoebe Unger | Amninder Singh Sekhon | Sonali Sharma | Alexander Lampien | Minto Michael



Nano bubbles rapidly reduce foulants within Three Mile Island water.

Earthman, J. C.; Dang, W “Alternating Magnetic Field Treatment of Service Water to Control Pitting Induced by Sulphate Reducing Bacteria”. *Corros. Manage.* 2010, 96, 11–14. EPRI Contract No. EP-P5436-C2692

Case Study

Seawater Fouling, proof-of-concept bubble perseverance

Seawater flow tubes



Fouling progression comparing air/control/iodinated air

Geothermal - Nano bubble downstream activity

A geothermal system at an 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.

Microchip Technology, Inc. (formerly Standard Micro Systems Corporation)

System gate valves



Recipient well screens



Since installing the vapor infusion system, the facility has **not** had to chemically or mechanically clean the heat exchanger.

ESTCP study compared two similar shell-and-tube heat exchangers, one infused and one used as control, onboard a working US Navy test ship

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*

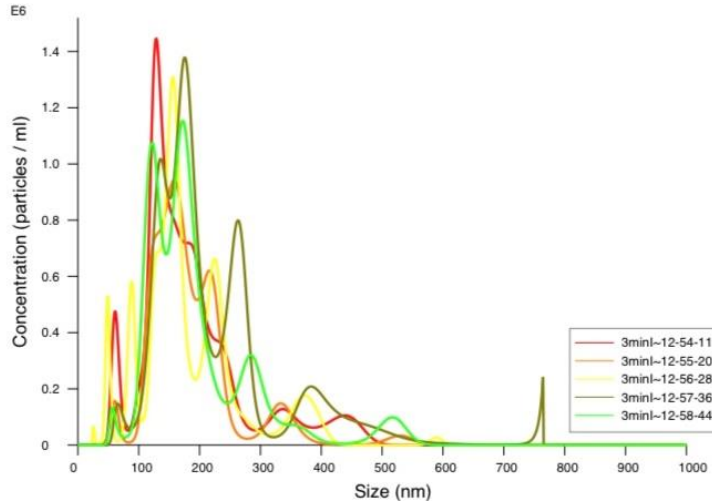
- Infusion duration was only 3 minutes per half hour, and total monthly cartridge iodine loss was less than 20 grams
- The infused exchanger was used 85% of time and still exhibited no biofouling



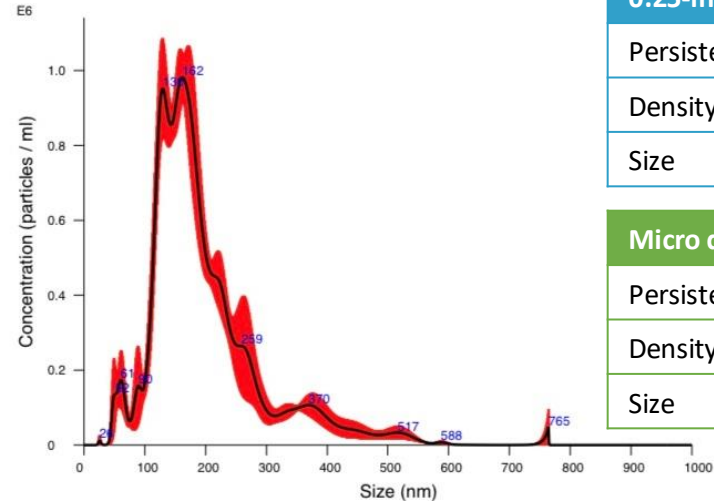
Nano bubble creation-3-minute infusion-UC Irvine

NANOSIGHT

3minl 2023-06-22 12-52-16



FTLA Concentration / Size graph for Experiment:
3minl 2023-06-22 12-52-16



Averaged FTLA Concentration / Size for Experiment:
3minl 2023-06-22 12-52-16
Error bars indicate + / -1 standard error of the mean

0.25-in. diffuser

Persistence	48 hours
Density	1.28 (10^8)
Size	158 – 196 nm

Micro diffuser

Persistence	192 hours
Density	3.77 (10^7)
Size	53 – 62 nm

Analysis conducted by Marco Ugalde-Valdés (Instituto Politécnico Nacional, Mexico City) while visiting the Earthman Labs at University of California, Irvine.

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**.*

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/seabed into all 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.



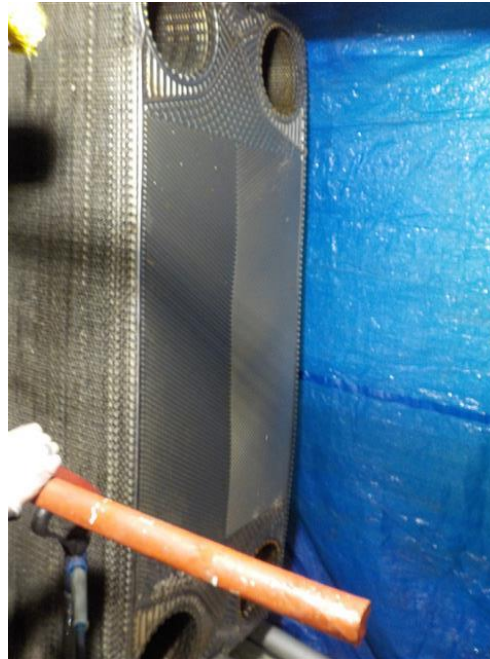
Cruise and cargo ships

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.

First Engineer on Norwegian Sun reported that all four LT coolers were found in good condition after a few years in operation.



Aft engine cooler
No biological or mineral fouling

Images used with permission of Norwegian Cruise Lines®

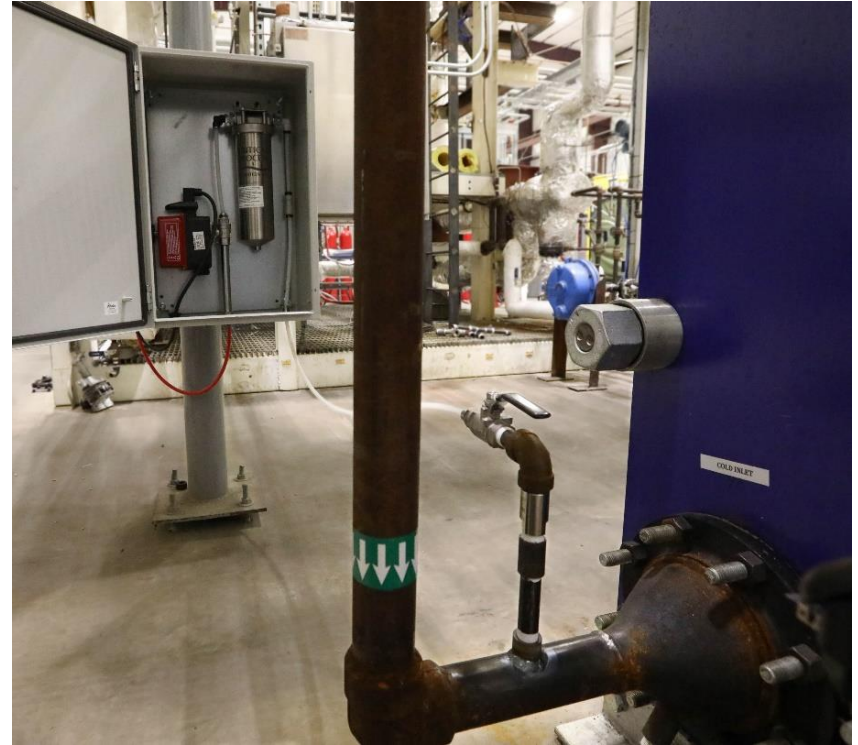


Forward engine cooler
No biological or mineral fouling

Simple integration, operation and low cost

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

- **air source:** Dry (entrained water removed), oil free, regulated at a flow rate 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 vapor infusion system control device (12-, 24-, 110-, and 220-volt systems available)
- **pipe connection:** NPT female pipe connection 2 – 4 ft. from heat exchanger water inlet



Infusion wand assembly

Red Tubing, from air source to device inlet

White tubing, air & vapor to infusion wand then heat exchanger

Benefits of vapor infusion:

- **Functional**
 - Improved performance
 - Improved energy and fuel use
- **Environmental**
 - Net Zero goals
- **Financial**
 - Reduced foul and function associated costs
- **Societal**
 - ESG score improvement
 - Positive marketing
- **Innovation**
 - New upcoming cutting-edge technology



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