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Improving Heat Exchanger Functionality with Nanobubble Technology to Achieve Net Zero Goals

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Climate change is a critical environmental issue for this and future generations. Natural and human-induced activities have already warmed the global average surface temperature by 1.1°C. There is international agreement that climate change requires an immediate response before the planet reaches a point after which it cannot recover. As the primary driver being a change in the earth's atmosphere, it is vital that companies, countries, and individuals do whatever is possible to reduce this condition. Greenhouse gases (GHG) are emissions including carbon monoxide, methane, sulfur dioxide, fluorinated gases, nitrous oxide, and others which are released into the atmosphere through both natural and industrial processes [1]. They are linked to environmental pollution and atmospheric temperature rise. Along with nitrogen, oxygen, helium, and other gases, they envelop the Earth as a blanket. GHG provides protection and predictable weather patterns by allowing ultraviolet and infrared wavelengths to warm the earth's surface and then mediating its escape back into space. Human activities, primarily through the combustion of fossil fuels, have upset the balance of the natural system allowing for an increase in atmospheric GHG. Due to an abundance of these gases the atmosphere can hold more heat, thus increasing the global temperature.

Carbon dioxide (CO_2) is a gas of great concern due to its abundance and robust emission profile when created through commercial activities during energy production. Increased CO_2 emissions have led to higher concentrations of it in the atmosphere. In 2021, CO_2 accounted for near 80% of all U.S. greenhouse gas emissions. Prior to expansive industrialization, and its compensatory rise in fossil fuel demand, CO_2, when released into the environment, was absorbed by the forests and the oceans. As GHG output has increased, the equilibrium between reabsorption and atmospheric presentation has fallen out of balance.

With the environment having reached and surpassed its limit for natural CO_2 absorption, Net Zero goals and methods are being adopted to help diminish industrial GHG expression [2]. These methods encompass artificial reabsorption coupled with technological improvements intended to reduce industrial CO_2 expression. Achieving the desired Net Zero goals on an industrial and global scale will require both primary and supplemental technologies. Although large-scale commercial reductions are vital, applying innovative science may be the most difficult to implement due to technological adoption resistance and financial costs. It is apparent that all industries need to look at the means to reduce their energy waste through existing system improvement by methods that can be implemented quickly and without excessive costs. Typically, the energy savings and improvement in functionality should compensate for the integration costs, thus allowing for a net sum gain rather than expense.

Heat Exchangers are Industry's low Hanging Fruit

A heat exchanger is a device that is used to transfer heat between a process and a cooling fluid during an industrial application. The term "thermal manipulation" best describes what a heat exchanger does. Although simplistic in design, their operational condition can significantly impact the day-to-day energy consumption of an industrial process and its carbon footprint. It is not their function but rather their malfunction, due to processes such as fouling, that heat exchangers can affect CHG emissions and energy expenditure.

Heat exchangers are foundational devices found in large numbers in all industries including nuclear power, chemical production, petroleum refining and propulsion generation. Typically robust, they are designed to compensate for potential inefficiencies to minimize excessive downtime or diminished functionality. Exchanger parameters to be considered for optimum function are exchanger size, plate surface area and importantly, cooling water flow characteristics. Unfortunately, even though sufficient design margins are anticipated, certain conditions, such as cooling water fouling (as seen in figure1), can elicit increased energy draw and thus excessive GHG. The results of this degrading functionality are expressed through reduced heat transference and increased back pressure within the cooling water system.

Figure 1: Biological Foul Formation

For a heat exchanger to function efficiently, it requires clean heat transfer surfaces and unimpeded cooling water flow. Fouling occurs when contaminants within the cooling water adhere and solidify on heat transfer surfaces and in flow spaces. This condition begins immediately after a clean heat exchanger is brought online. Although not immediately apparent, as foul formations increase in density or dimension, there is an ever-decreasing function expressed by the exchanger. Each exchanger requires a specified cooling water volume, speed, and pressure to ensure heat extraction. This is not achieved if there is impeded flow space or misdirection away from heat transfer surfaces. Obstructions reduce flow volume which causes increased back pressure across the exchanger. Furthermore, on heat transfer surfaces, the foulants function as thermal insulators reducing the transfer of heat from one fluid to another. Sensors will demand greater water flow from the cooling water pump as a response to a temperature and pressure rise. To compensate, the pump increases water output necessitating increased energy draw. This energy is typically from a source that uses fossil fuel combustion for electrical energy production. Even a small, incremental rise in pump demand due to foul formation can often translate to measurable increases in GHG generation (see figure2). There is an ever-increasing decline in function (and corresponding increase in energy draw) that continues until an acute condition, such as total malfunction, requires an emergency disassembly. Unfortunately, due to the importance of a heat exchanger within a process system, they are not readily taken offline to clean and are typically tolerated until and when an issue arises.

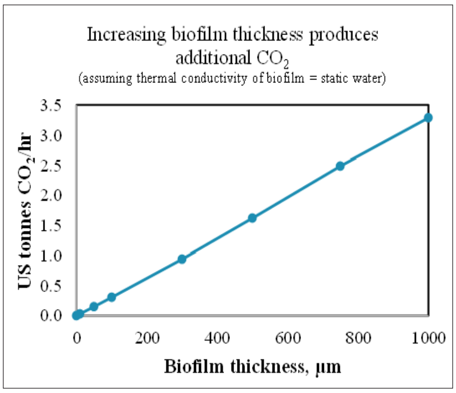

Figure 2: Correlation between the Biofilm Thickness Atmospheric Release of CO_2

The above graph is from one of the many papers that have indicated the relationship between heat exchanger fouling and its environmental impact [3,4]. The paper concluded the following.

- "…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."

For decades, industry has borne the financial expense and challenges presented by heat exchanger fouling because of the difficulty of remediation or prevention. It was understood that there was a fiscal impact of maintenance, repair, excessive energy, and loss of process which could reach .25% of an industrialized country's GNP due to fouling [5]. These challenges were tolerated since the results of these inefficiencies were only felt by the facility. It was the advent of climate change and an understanding that each malfunctioning heat exchanger offers a compounding impact on environmental global events. It is now universally accepted that there is a need to reduce GHG expression from industrial process systems by utilizing a sustained method to prevent fouling in heat exchangers.

Nanobubbles

Nanobubbles (NBs) are nanoscopic gaseous structures having a diameter of less than two hundred nanometers that can exist in liquids or interact or attach to submerged surfaces. They are of great interest for industrial and medical real-world application in that they offer longevity and stability in water while providing high gas transfer rates [6]. They undergo Brownian motion within a fluid which is the random dispersal of particles suspended in a medium. Unlike macro or micro bubbles that will rise and coalesce, this pattern is comprised of random movement by the bubbles in all directions within a fluid and vessel. This enables them to continuously stimulate physical, biological, and chemical interactions between the bubble surfaces and components within the fluid through contact, electrostatic interaction, or penetration [7]. It is this capability that has been shown to induce the removal of fouling mineral sites on surfaces and cause free floating fouling agents to not bind [8,9]. This motion also provides for the volumetric presentation of the bubbles throughout a fluid stream and due to their size a much greater surface area than microbubbles. These capabilities were evident at a study performed to alleviate pitting caused by sulfate-reducing bacteria at the Three Mile Island Nuclear Power Station where NB presentation reduced and eliminated surface foul [10]. Furthermore, NBs have been used to clean stainless-steel surfaces of foulants which are commonly found in many fluids borne industrial processes [11].

In recent years, there has been an ever-growing interest on how nanobubbles have an effect on heat exchanger function and fouling. This is a logical extension from the prior research performed that indicates micro and/or macro bubbles will have a foul inhibiting effect within heat exchangers, improve heat transfer and disrupt biofilms [12-14]. Unfortunately, the presentation of larger bubbles into a flow stream can create conditions that are deleterious or non-productive within a system. Bubbles will coalesce within a horizontal flow stream thus reducing or eliminating the potential for lower or side pipe surface interaction. Furthermore, air pockets can occur within a high point or pipe bend which can influence fluid flow creating back pressure. Dependent of system design, if these bubbles are introduced prior to a pump, they could interfere with pump function or create cavitations potentially causing damage. Although the presentation of air micro or macro bubbles may be offered as a dynamic system purge, it will not provide for the benign, systemic benefits that NBs may offer.

As previously mentioned, fouling is an insidious condition that begins immediately after a newly cleaned system is brought back online. Therefore, it is imperative that an anti-fouling technology be utilized that would operate during heat exchanger function and NBs may hold promise. There are numerous studies that indicate that NBs are capable of foul remediation through their interaction with crystalline fouling structures and the inactivation of microbes within biofilms [15,16]. Although NBs may have foul remediating or preventative capabilities, they may also maintain or improve heat transfer through varying means such as the creation of wake zones, disrupting insulating foul formations and increasing the thermal conductivity of a fluid [17,18]. It has been shown that NBs can allow for more efficient heat transfer through the disruption of boundary layers and the creation of micro-convections within the fluid. When presented into a fluid, NBs have led to improved heat transfer rates when compared to a fluid without nanobubbles [19].

For small-scale scientific investigation or low volume applications, the method of nanobubble creation is determined by the bubble size desired. To generate nonspecific high-volume bulk fluid nanobubbles for use in large commercial applications various methods have been utilized [20]. These may include liquid flow generators that use membranes, static mixing, swirling liquid flow, shearing and pressurized dissolution to create nanobubble emulsions of significant density [21]. These techniques for nanobubble creation require water flow manipulation or excessive energy use. Alternating magnetic fields, vapor infusion and other benign methods can create dense emulsions of NBs continuously, without excessive expenditure of energy or water [22,23]. Regardless of method chosen, the unique characteristics of NBs present themselves as a potential means to reduce the impact of fouling.

The Important Role of Heat Exchangers on Net Zero Goals

The ever-growing global concern about excessive expression of GHG into the atmosphere, particularly from industry, has begun a revolution whereby corporations are becoming environmentally aware. Due to external forces such as public acceptance and financial pressure, companies utilize tools, such as their ESG score (in which "E" stands for Environmental) to identify the potential areas of improvement. The relevance of ESG reporting has grown as investors and other corporate stakeholders desire to invest in or work with companies that wish to undertake the current environmental, economic, public health and social justice crises. Additionally, ESG reporting provides a roadmap offering guidance to the public and consumers by which to measure the company's environmental and social stance. Consumers are now driven by how and where a product is manufactured and that process's impact on the environment. An unbiased source available to those concerned about registered ESG ratings is the CDP (the Carbon Disclosure Project) which is a non-governmental organization that focuses on environmental factors.

The environmental portion of a company's ESG score reflects its carbon footprint, energy efficiencies, greenhouse gas emissions, waste management and water usage. This portion identifies how a company performs as a steward of the physical environment and its use of innovation. This is vital since climate change and Net Zero goals figure very prominently in ESG discussions and application. This score will illuminate a company's utilization of natural resources and the effect that their operations will have on the environment, which is of great concern to all populations and generations. The relationship between industrial actions and global warming has become obvious. The increased frequency of weather-related events like wildfires, hurricanes, floods, and heatwaves is apparent on social media and newscasts. Of significant importance therefore is industry's integration of innovative and technologically adept methods that can impact GHG expression. The race to achieve Net Zero CHG emissions has begun with an internationally agreed upon goal for mitigating global warming by the second half of the century. The Paris Agreement concluded that it could be achieved by net zero emissions of CO_2 by 2050. To achieve this, industry will need to look at all aspects of their process systems and uncover not only the cutting edge but also the mundane GHG savings that may offer significant impact.

The correlations between heat exchanger function, its energy use and greenhouse gas expression are clear. Although there are numerous methods to reduce a company's carbon footprint, none are as direct as the improvement in function of a benign device such as the heat exchanger. The Yale School of Environment states that "Every bit of waste heat recycled into energy saves some fuel." Thermal management is one of the key indicators of environmental stewardship. Integrating technology that offers improved heat exchanger sustainability and functionality can help allow a company to claim ESG leadership. It is obvious that the costs associated with complying with many Net Zero goals can be daunting, so it is vital to integrate those technologies that offer the best, most easily attainable results. Improving heat exchanger performance does this while achieving meaningful energy and carbon savings, continually, without excessive intervention or costs and should improve the Innovation portion of a company's Environmental ESG score.

Author's Note

As mentioned within the paper, global warming and carbon dioxide expressions have an insidious, generational impact. While researching and writing this paper it was vital that the younger generation have both input and review. I relied upon their passion and concerns to understand the urgency presented by global warming.

For information regarding vapor infusion please reach out to the author.

About the Authors

Michael Radicone is president and chief science officer of I2 Air Fluid Innovation and Specialty Product Lead for HTRI. I2 Air Fluid Innovation has developed and patented technologies that address heat exchange fouling, toxic mercury presence in fluids and flue gas scrubber enhancement. As specialty Product Lead for HTRI, he oversees development and integration of the Vapor Nano Bubble Infusion technology. The recipient of seven governmental grants, he is published and peer reviewed and has presented the technology worldwide.

Grace Angela Witt is a Junior Biomedical Engineering student at Clemson University with a concentration in Biomaterials. She works on an undergraduate research team titled Polymeric Biomaterials for Treatment and Diagnosis of Central Nervous System Disease through the Creative Inquiry program at Clemson University. In this project she works under Dr. Larsen, a professor in the Chemical and Biomolecular Engineering Department, and is researching how when polymersomes are modified with salts, the protein interactions change in serum.

Ryan Radicone is a student researcher who is investigating the application of a technology that delivers a therapeutic drug utilizing a human hair derived keratin 3D scaffold model. The research is intended to determine the scaffold's biocompatibility and bioreactivity of its surface area for both the loading and timed release of therapeutic drugs.

Bruce Birdwell is a graduate of SUNY At Stony Brook with a BS in Biology & Professional Engineering credits from University of Texas and Louisiana Technology. Career positions have been with Veeco Instruments, Metrology NDE, District Sales Manager, IBA (Ion Beam Application), Particle Accelerators, North America Sales Manager, 3M EMD, Product Launch of SIPP for Potable Water Rehabilitation, Sales Manager, Framatome, SIPP and Coatings for Nuclear Applications, Product Manager & Business Development

References

1. Manabe S (2019) Role of greenhouse gas in climate change. Tellus A: Dynamic Meteorology and Oceanography 71: 1-13.
2. Mohammed Ouikhalfan, Omar Lakbita, Achraf Delhali, Ayalew H Assen, Youssef Belmabkhout (2022) Toward Net-Zero Emission Fertilizers Industry: Greenhouse Gas Emission Analyses and Decarbonization Solutions. Energy Fuels 36: 4198-4223.
3. Casanueva Robles T, Bott TR (2005) The environmental effect of heat exchanger fouling: A case study. ECI Symp Ser, Kloster Irsee, Germany RP2: 278-282.
4. Müller-Steinhagen H, Malayeri MR, Watkinson AP (2009) Heat exchanger fouling: Environmental impacts. Heat Transfer Eng 30: 773-776.
5. Müller Steinhagen H, Malayeri MR, Watkinson AP (2005) Fouling of Heat Exchangers-New Approaches to Solve an Old Problem. Heat Transfer Engineering 26: 1-4.
6. Foudas AW, Kosheleva RI, Favvas EP, Kostoglou M, Mitropoulos AC, et al. (2023) Fundamentals, and applications of nanobubbles: A review. Chem Eng Res Des 189: 64-86.
7. Liu S, Kawagoe Y, Makino Y, Oshita S (2013) Effects of nanobubbles on the physicochemical properties of water: The basis for peculiar properties of water containing nanobubbles. Chem Eng Sci 93: 250-256.
8. Tagomori K, Kioka A, Nakagawa M, Ueda A, Sato K, et al. (2022) Air nanobubbles retard calcite crystal growth, Colloids and Surfaces A: Physicochemical and Engineering Aspects 648: 129319.
9. Wu Y, Huang M, He C, Wang K, Nhung NTH, et al. (2022) The influence of air nanobubbles on controlling the synthesis of calcium carbonate crystals. Materials 15: 7437.
10. Earthman JC, Dang W (2010) Alternating magnetic field treatment of service water to control pitting induced by sulphate reducing bacteria. Corrosion Mgmt 96: 11-14.
11. Chen H, Mao H, Wu L, Zhang J, Dong Y, et al. (2009) Defouling and cleaning using nanobubbles on stainless steel. Biofouling 25: 353-357.
12. Baek SM, Seol WS, Lee HS, Yoon JI (2010) Decreasing the fouling of heat exchanger plates using air bubbles. Defect and Diffusion Forum 297: 1199-1204.
13. Chang SW, Huang BJ (2013) Thermal performance improvement by injecting air into water flow. Intl J Heat Mass Transfer 57: 439-456.
14. Jang H, Rusconi R, Stocker R (2017) Biofilm disruption by an air bubble reveals heterogeneous age-dependent detachment patterns dictated by initial extracellular matrix distribution. NPJ Biofilms Microbiomes 3: 1-6.
15. Anastasios W Foudas, Ramonna I Kosheleva, Evangelos P Favvas, Margaritis Kostoglou, Athanasios C Mitropoulos (2023) Fundamentals and applications of nanobubbles: A review. Chemical Engineering Research and Design 189: 64-86.
16. Shiroodi S, Schwarz MH, Nitin N, Reza Ovissipour (2021) Efficacy of Nanobubbles Alone or in Combination with Neutral Electrolyzed Water in Removing Escherichia coli O157:H7, Vibrio parahaemolyticus, and Listeria innocua Biofilms. Food Bioprocess Technol 14: 287-297.
17. Bayazit BB, Hollingsworth DK, Witte LC (2003) Heat transfer enhancement caused by sliding bubbles. J Heat Transfer 125: 503-509.
18. Amburi PK, Senthilkumar G, Mogose IN (2022) Heat transfer augmentation: Experimental study with nanobubbles technology. Advances in Materials Science and Engineering 2022: 1-3.
19. Senthilkumar G, Purusothaman M, Rameshkumar C, Nivin Joy, Sachin S, et al. (2021) Generation, and characterization of nanobubbles for heat transfer applications. Materials Today: Proceedings 43: 3391-3393.
20. Favvas EP, Kyzas GZ, Efthimiadou EK, Mitropoulos A Ch (2021) Bulk nanobubbles, generation methods and potential applications. Current Opinion in Colloid and Interface Science 54: 101455.
21. Alam HS, Sutikno P, Soelaiman TAF, Sugiarto AT (2022) Bulk nanobubbles: Generation using a two-chamber swirling flow nozzle and long-term stability in water. J Flow Chem 12: 161-173.
22. Quach V, Li A, Earthman JC (2020) Interaction of calcium carbonate with nanobubbles produced in an alternating magnetic field. ACS Applied Materials and Interfaces 12: 43714 -43719.
23. Mc Elrath J (2022) A study of iodine vapor infusion to mitigate fouling of cooling tower water. Proc 2022 Horizons Symposium https://www.htri.net/horizons/water-quality/a-study-of-iodine-vapor-infusion-to-mitigate-fouling-of-cooling-tower-water.