Assessment of ozone micro-nano bubble technology for fresh water cooling towers in HVAC systems

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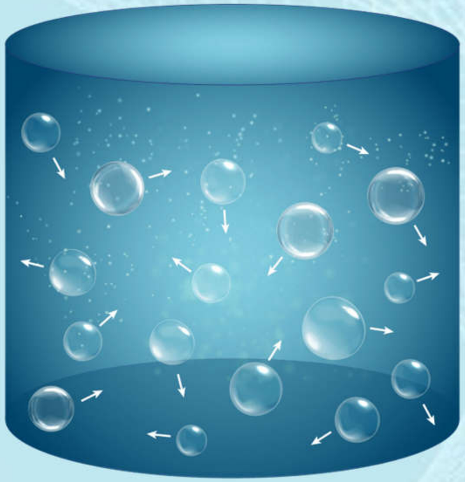
Contents



Acknowledgments
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1. Introduction

- Micro-nano bubbles (MNBs):
  - Very fine gas bubbles with diameters in micrometers & nanometers
  - Typical diameter:
    - Microbubbles (MBs) - 10-50 micrometer
    - Nanobubbles (NBs) < 200 nanometer
- Wide applications in many fields of science & technology, such as water treatment, biomedical engineering, and nanomaterials
- Combination of the MNB technique with ozone could provide an efficient approach for improving water treatment in HVAC

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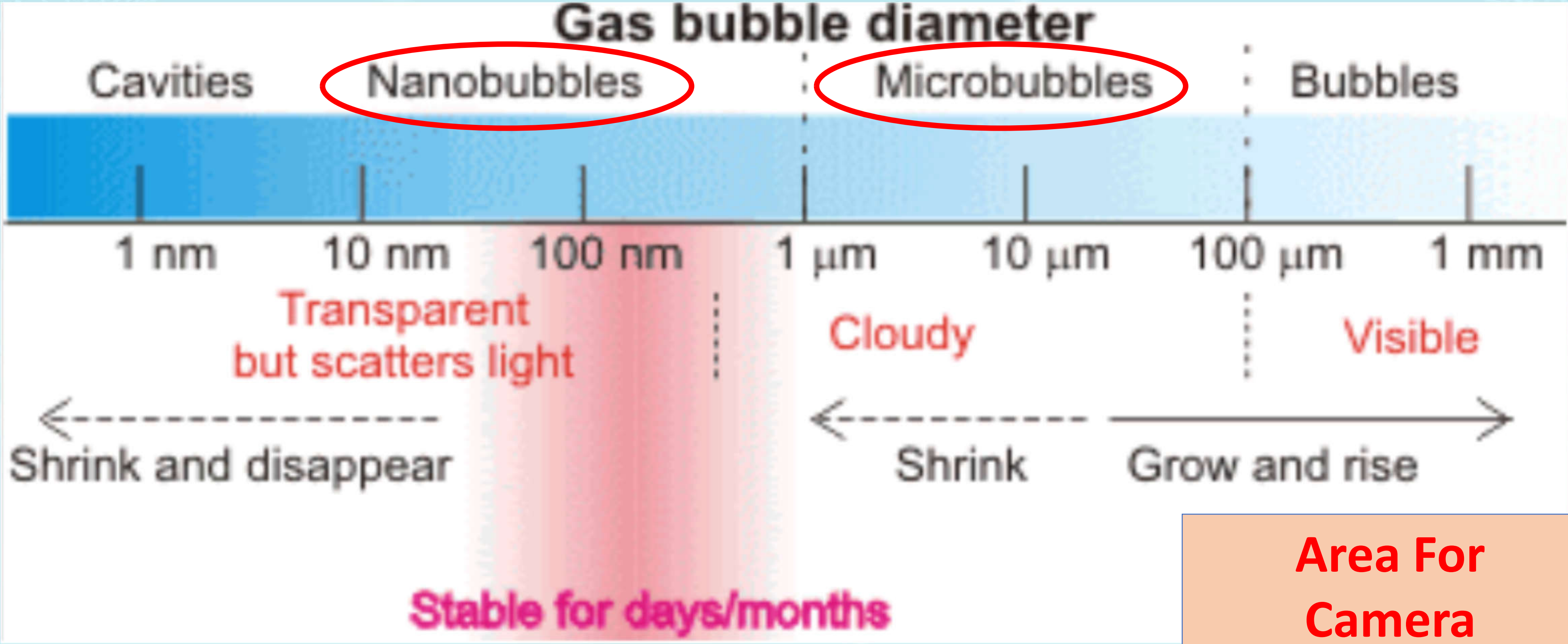
Overview of gas bubble size



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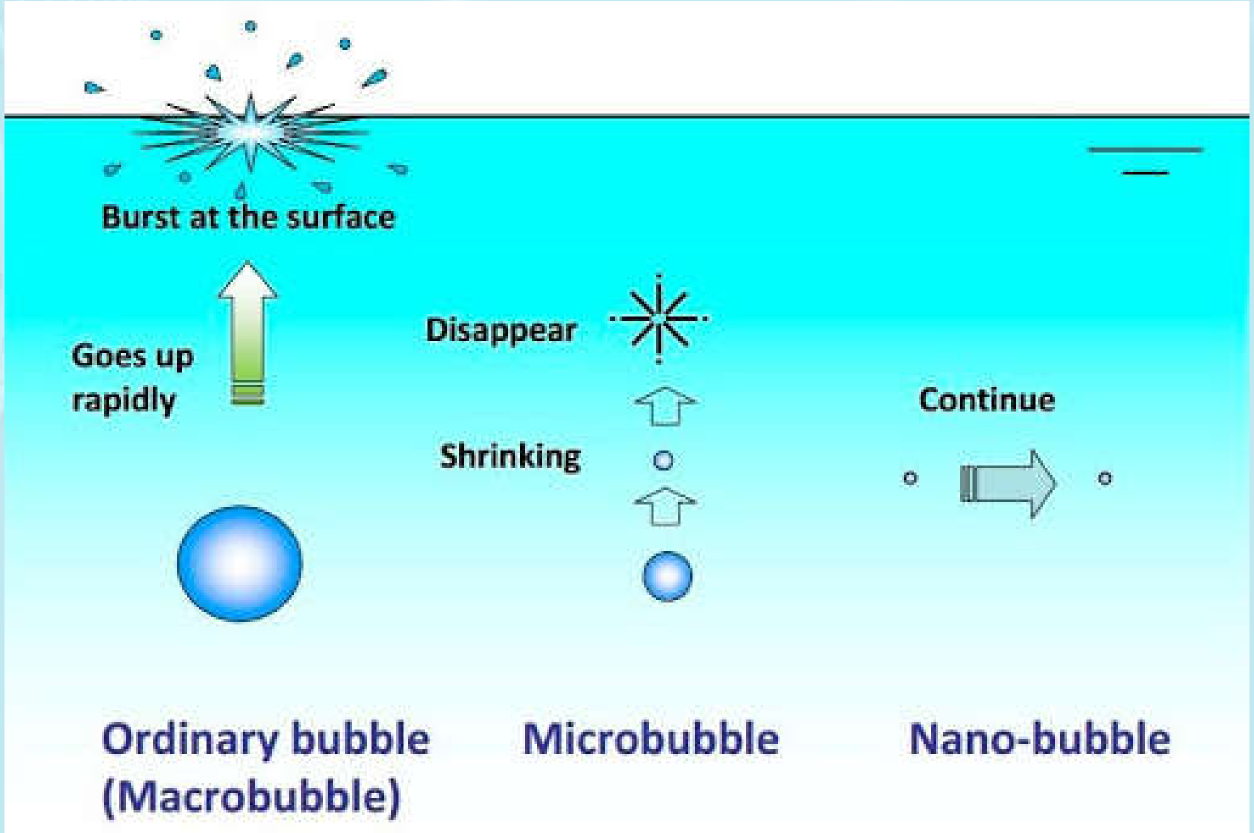
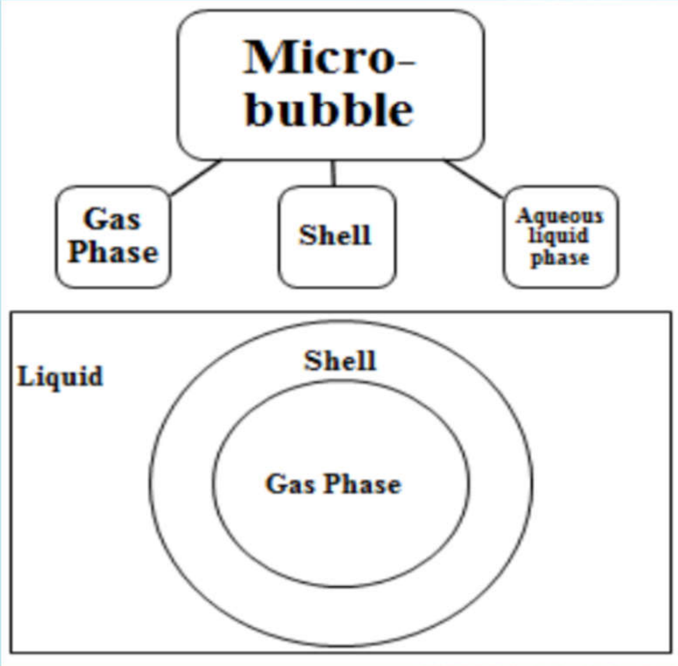
(Image source: http://oxydoser.com/)

Basic concepts of macro, micro & nanobubbles



[Refs: (Takahashi, 2017); (Arumugam, 2015)]

Basic components of a microbubble



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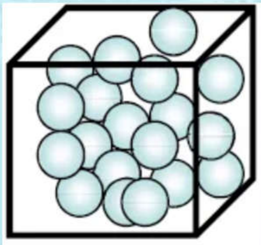
2. Principles of Micro-nano Bubble Technology



- Bubble formation, coalescence (merging) & break up
- Microbubbles (MBs)
  - Generate free radicals when they break into nano sized bubbles called ultrafine bubble or NB
  - The external electrostatic pressure created by the charged NB interface, balances the internal Laplace pressure; therefore, no net diffusion of gas occurs at equilibrium & the NBs are stable
- Water-related applications of MNBs
  - Water treatment, water purification, environmental pollution control, groundwater bioremediation, wastewater treatment & minerals engineering
  - Commonly known processes in water treatment utilizing bubble technology are floatation, aeration, disinfection & advanced oxidation processes

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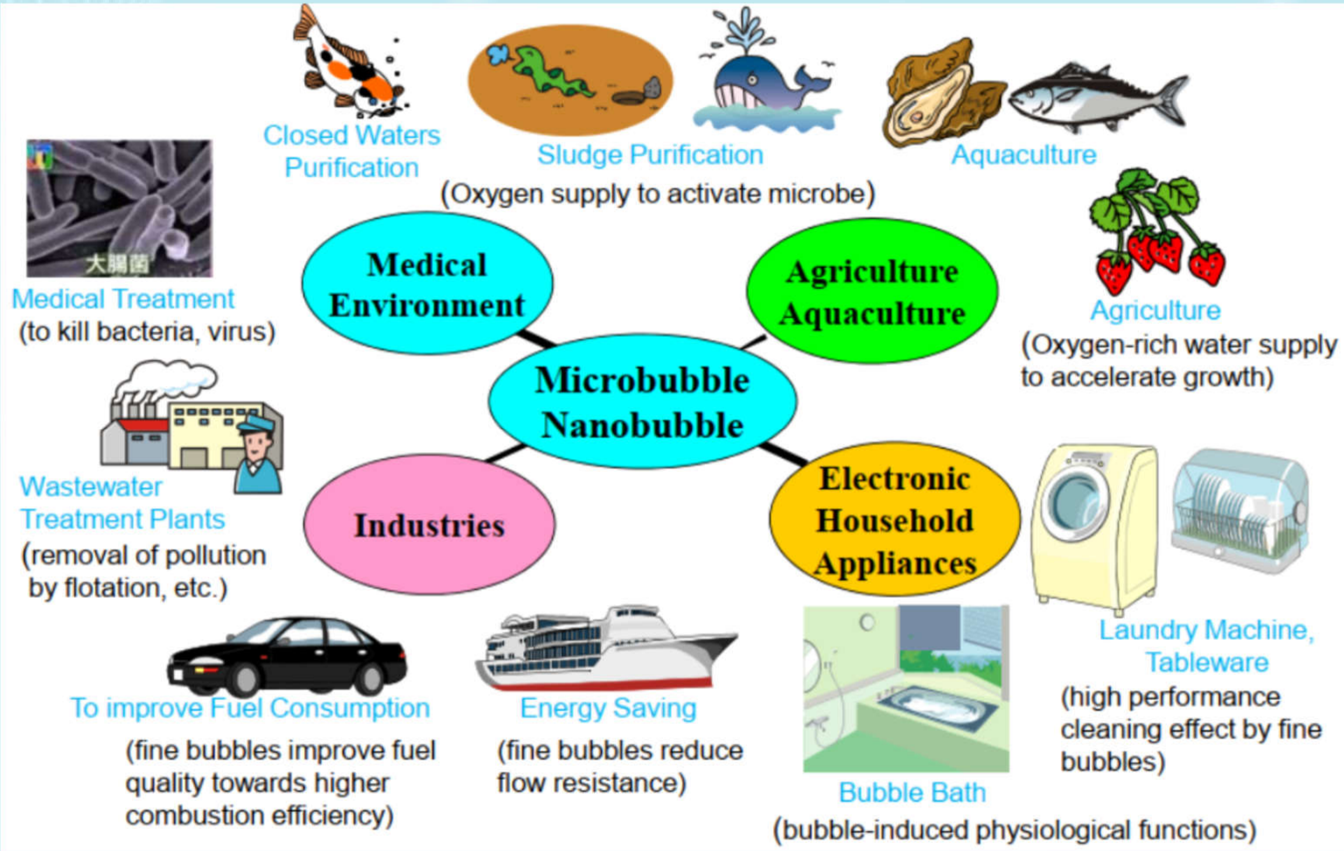
Recent trends in practical applications of micro-nano bubble technology



(Source: Prof. Akimi Serizawa, Kyoto University, Japan)

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3. Ozone Integrated with Micro-nano Bubbles

- Ozone is a powerful disinfectant for water purification
  - Oxidation of compounds via ozone molecule (direct reaction)
  - Oxidation through the reaction of the compound with the hydroxyl radicals formed from ozone (indirect reaction)
- Limitations of ozone: low mass transfer efficiency, low saturation solubility & short half-life
- Ozonation process in water treatment can be enhanced economically by using the MNB technology
  - Creates positive synergetic effects on solubility, stability & mass transfer efficiency (prolong reactivity of ozone & improve the decomposition rate)

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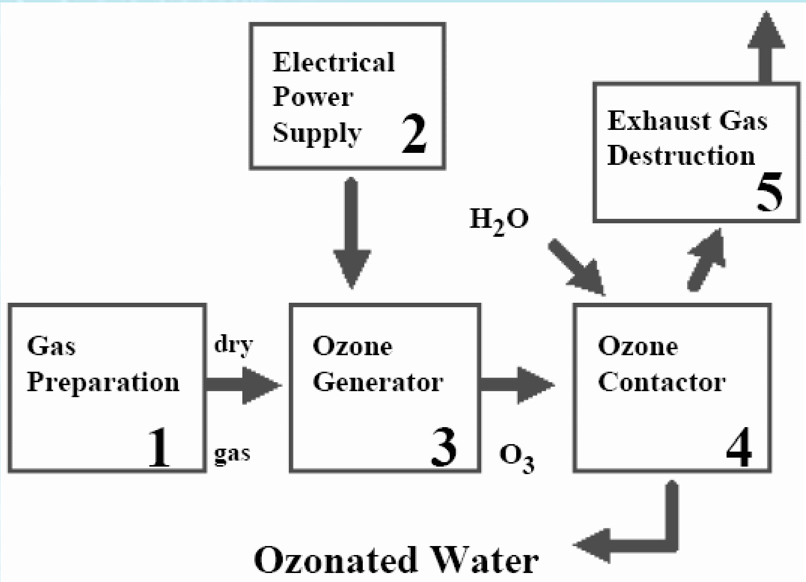
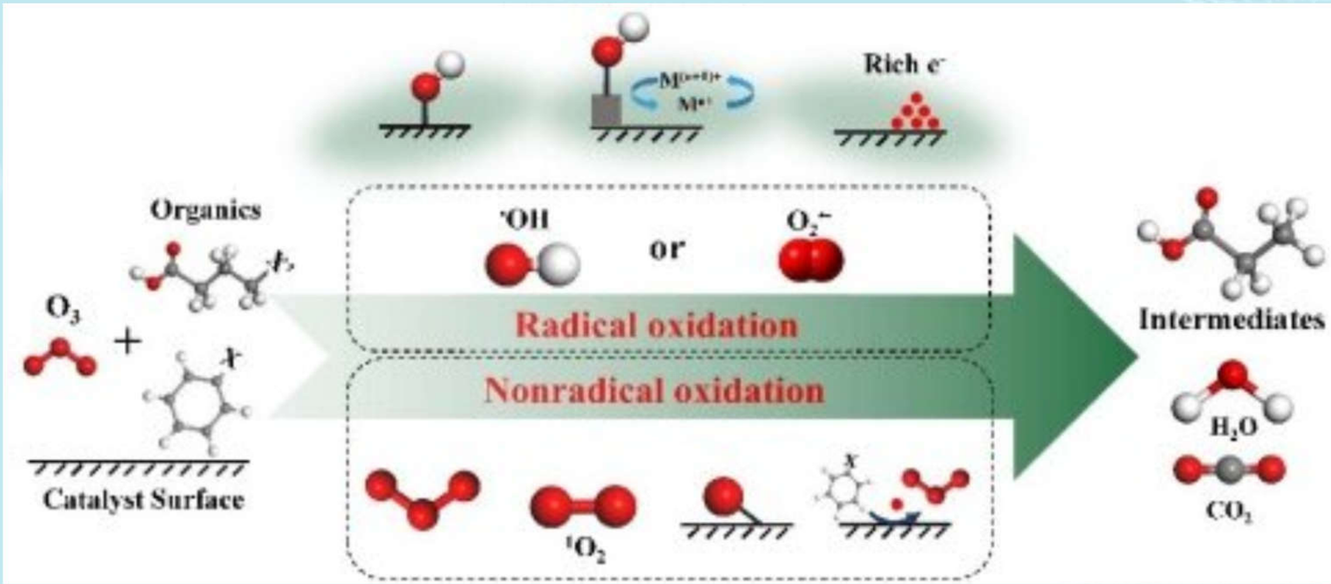
Typical water ozonation process & oxidation methods





[Refs: (Takahashi *et al.*, 2012); (Takahashi *et al.*, 2016)]

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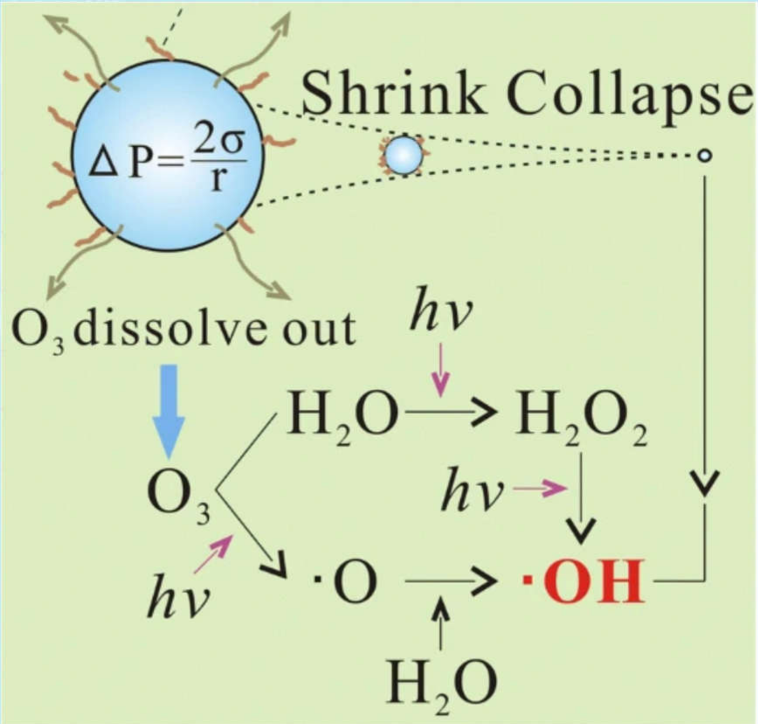
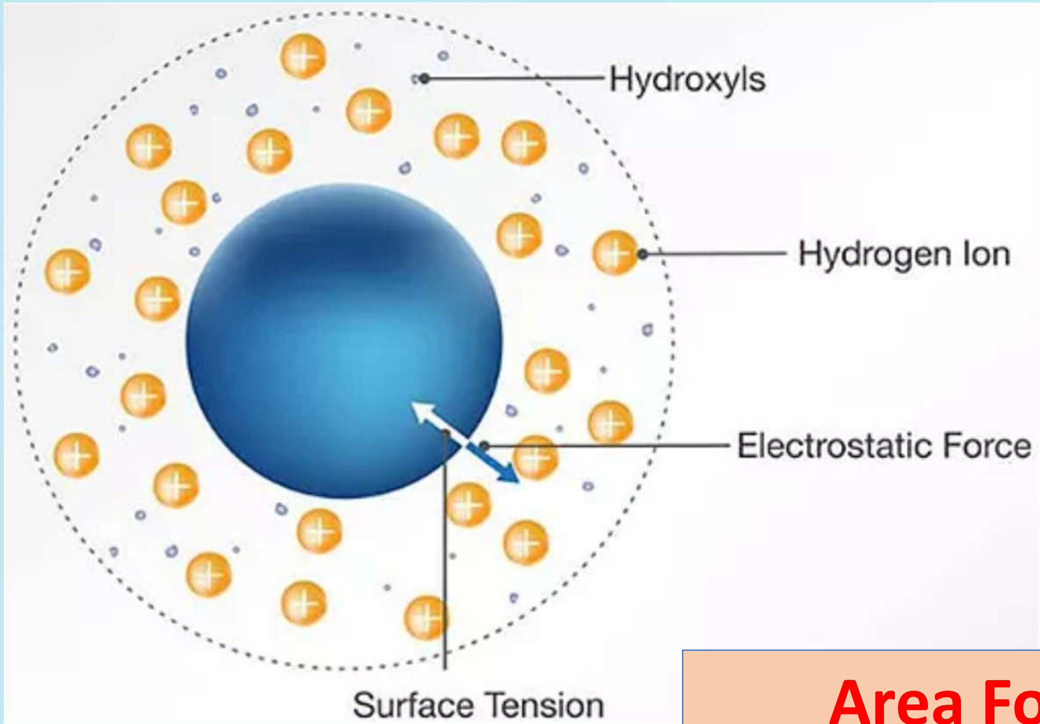
Intensify ozonation using MNB technology





[Ref: (Gao *et al.*, 2019)]

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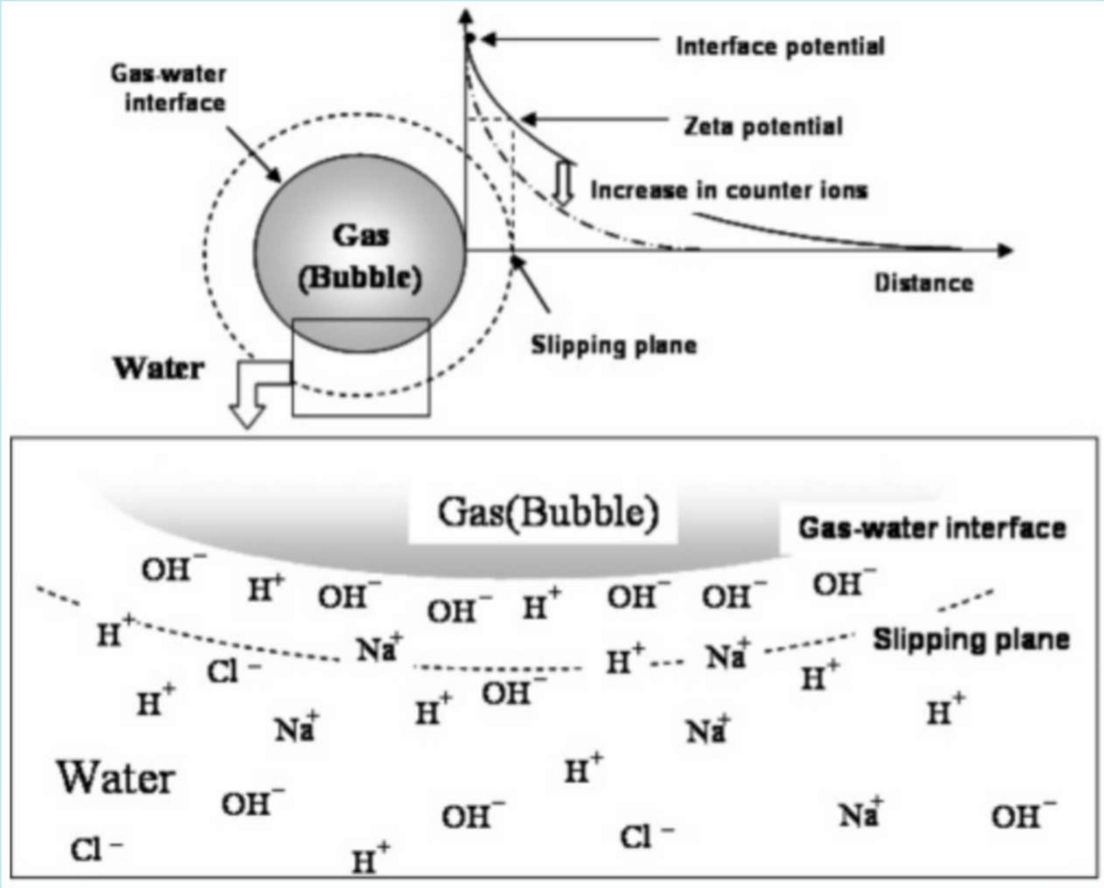
Distribution of ions at & near the gas-water interface



[Ref: (Takahashi, 2005)]

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Characteristics of micro-nano bubbles (MNBs)

- 1. Small bubble size
- 2. Slow rising velocity
- 3. Decreasing friction drag
- 4. High pressure inside the bubble (self-compression effect)
- 5. Large interfacial area
- 6. Large gas dissolution
- 7. Dissolution & contraction of MNBs
- 8. Negatively charged surface

[Ref: (Tsuge, 2015)]

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4. Benefits and Key Considerations

- MNBs are able to catalyze chemical reactions, inactivate pathogens, mitigate biofouling & enhance the detoxification efficiency, thereby improving the efficiency of chemical & biological treatment of water

- Can help reduce biological, chemical & physical loads in order to reduce the running costs & increase the treated water quality

- Can generate free radicals during the collapsing process under water & this is a very effective property for surface cleaning

- Can increase the concentration of ozone & hydroxyl radical (·OH) which will help achieve efficient reduction of oxidative chemical oxygen demand (COD) of the treatment process

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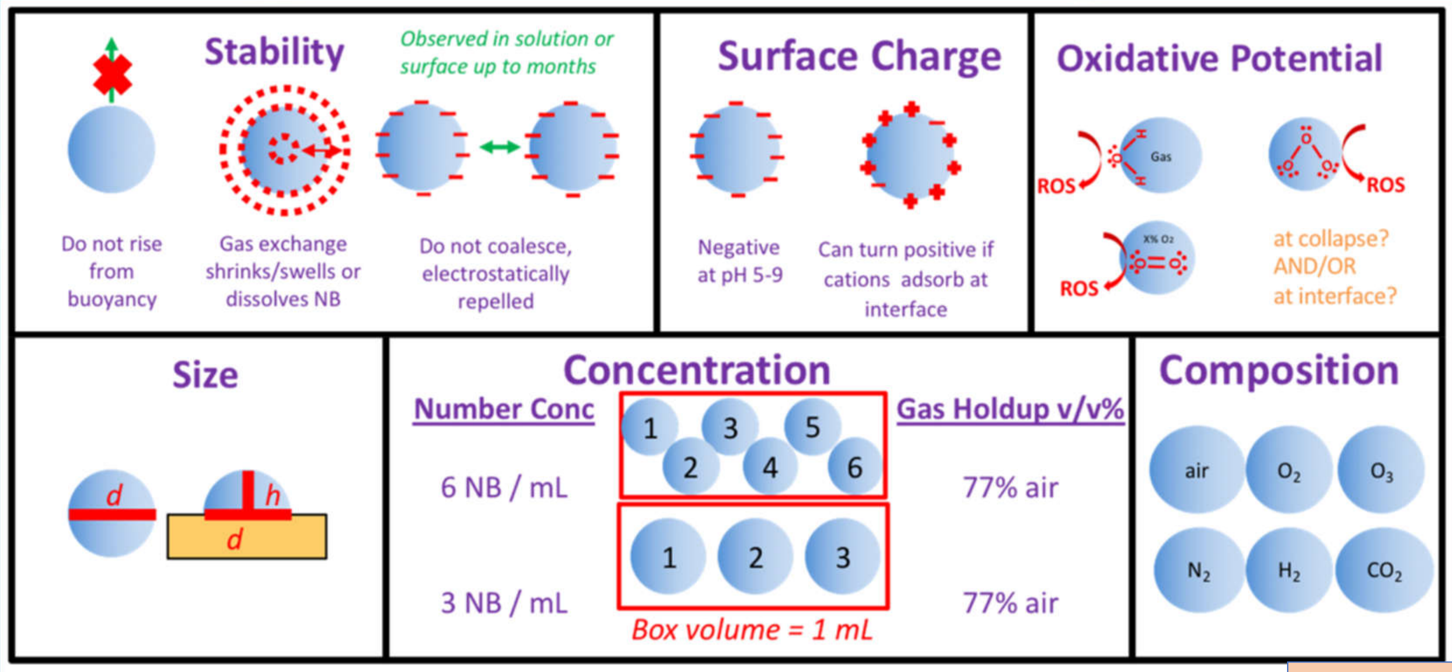
Unique physicochemical characteristics of nanobubbles (NBs)



[Ref: (Atkinson *et al.*, 2019)]

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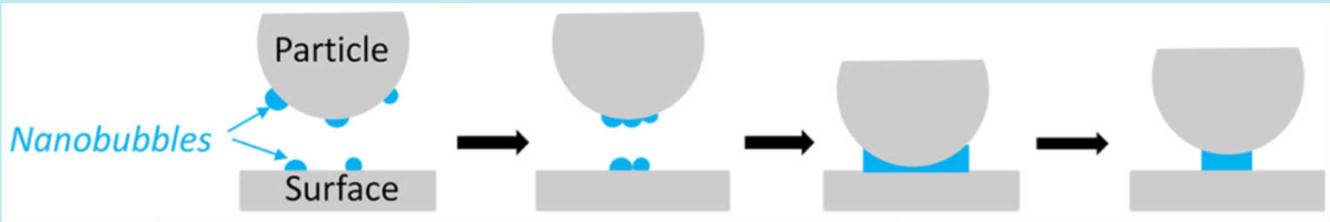
4. Benefits and Key Considerations

- Potential benefits for HVAC applications
  - Economic benefits: downsize the facilities, reduce operation & maintenance cost of water treatment, enhance chiller energy performance
  - Environmental benefits: effluent disposal reduction, water & energy conservation, reduction of greenhouse gas emissions
  - Social benefits: safety & health impacts; reduce or replace the use of chemical detergents or disinfectants & minimize the risk of chemical allergy

- Can form gas bridges that enhance particle-particle aggregation to aid in particulate or surfactant removal (surface cleaning & defouling)



[Ref: (Atkinson *et al.*, 2019)]

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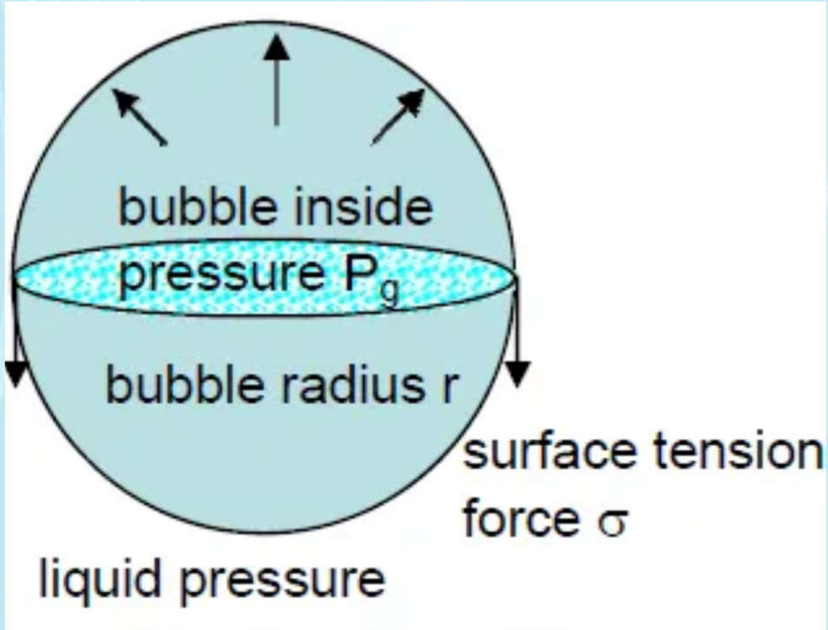
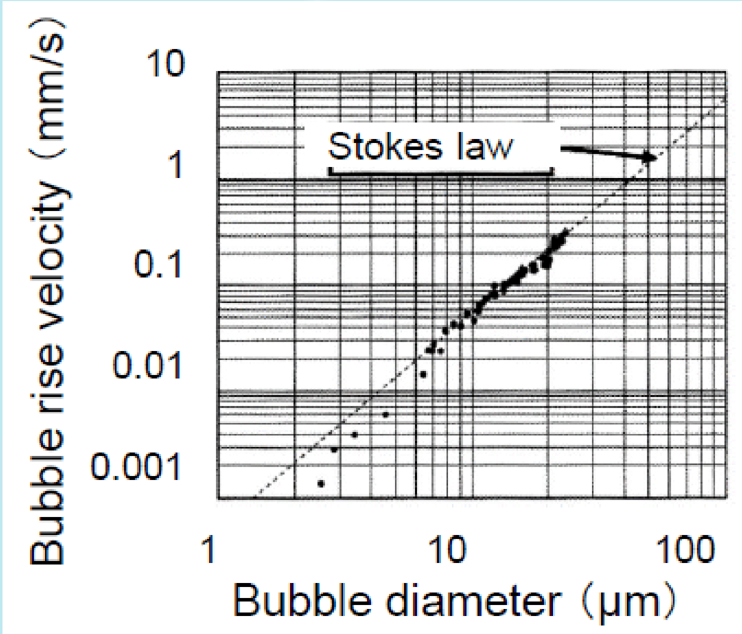
Key considerations of MNB technology



Bubble size & internal pressure



Bubble rise velocity

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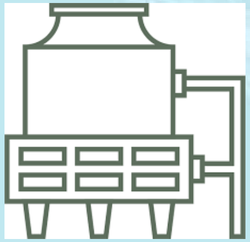
Mass transfer rate from gas to liquid (mol/s): $N = \frac{k_L A1(p - p^*)}{H}$

5. Application to Fresh Water Cooling Towers in HVAC Systems



- Cooling tower evaporation
  - A high percentage of the materials dissolved in the water
  - Appreciable quantities of airborne impurities may enter during operation
- During the condensation process soluble minerals are deposited as scale in the condenser tubes & microscopic plant matters tend to deposit as biofilm in the condenser tubes
- Without proper water treatment, corrosion & scaling occurs in the pipes & basin which results in poor heat transfer & renders the cooling tower inefficient
- Ozone water treatment can be enhanced by using MNBs

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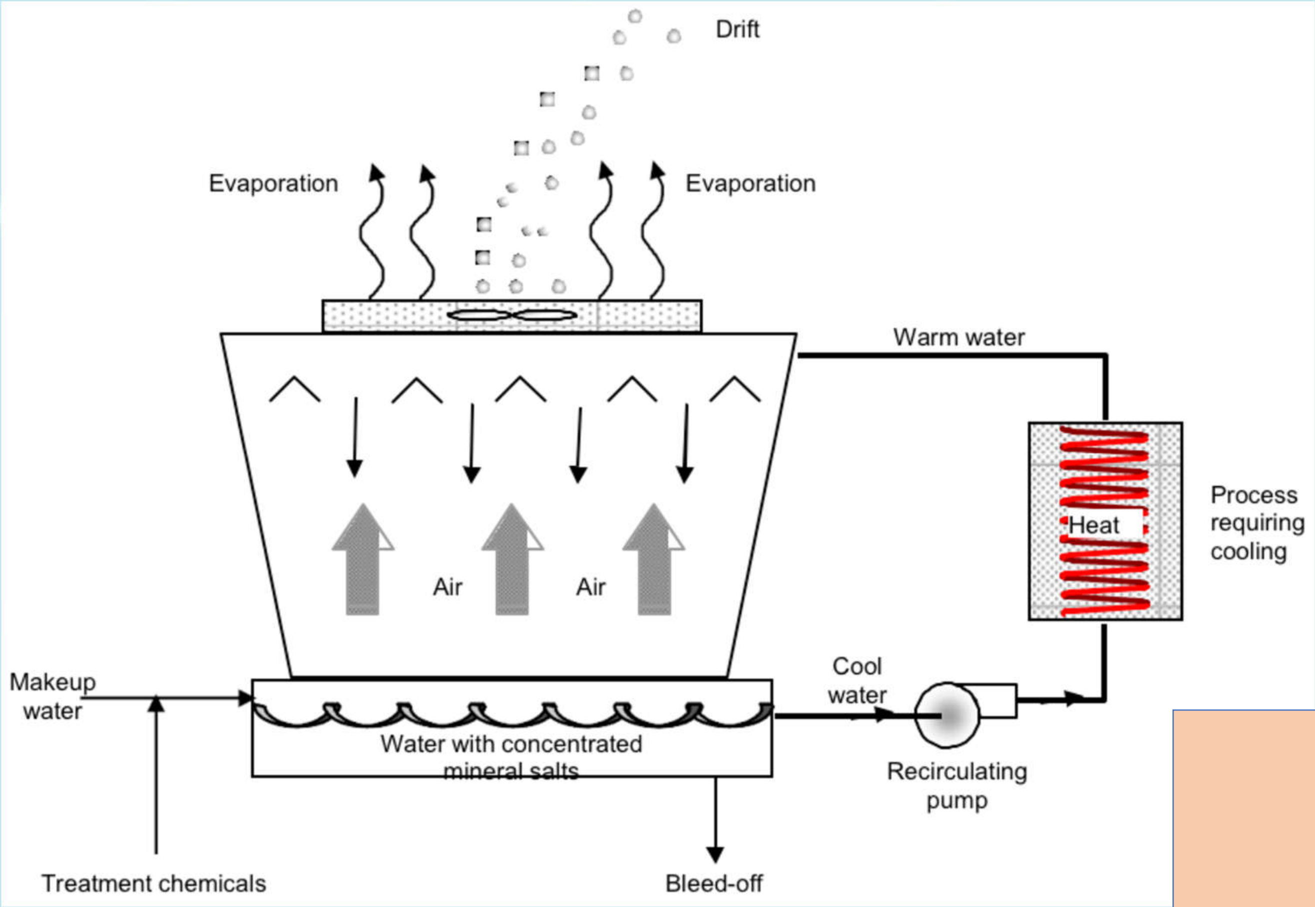
Schematic diagram of a cooling tower system



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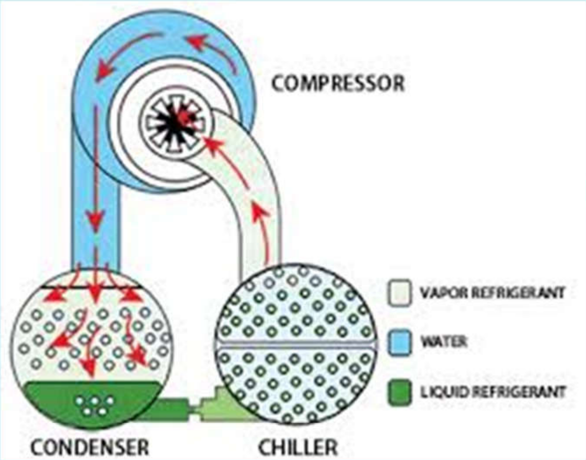
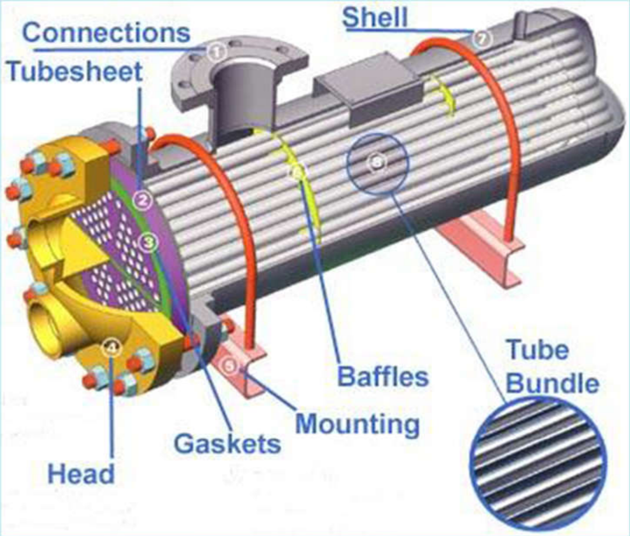
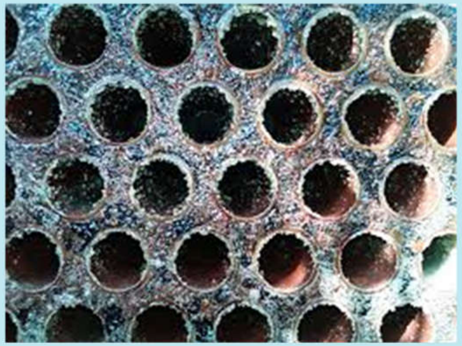
Condenser tubing & fouling effects







(Image source: https://ahrinet.org/contractors?S=134)

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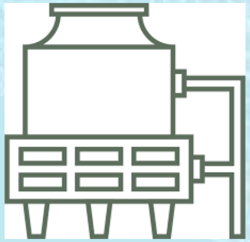
5. Application to Fresh Water Cooling Towers in HVAC Systems



- By injecting ozone gas into the cooling water in the form of ultrafine bubbles, it is possible to achieve higher levels of dissolved ozone in the water & allow the dissolved ozone to remain present in water for a much longer time
- The use of NBs to mitigate fouling
  - NBs control biofilm formation through directly acting on microbes & indirectly acting on water quality
  - NBs could interact & inactivate bacteria that often foul membrane or other surfaces through disruption of cell structure
  - The vibrational motion of NBs may induce shear forces that disrupt biofilms, leading to reduced chemical usage & energy-intensive washing

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6. Discussions

- Fouling in cooling towers
  - Affects the heat transfer surfaces of water-cooled condensers
  - Fouling factor is defined as the thermal resistance due to the accumulation of contaminants on the water-side of the heat transfer surface
- In many buildings & facilities, chillers are the largest energy-using component
  - As the fouling factor increases, both the condensing temperature & power input will rise due to poor heat dissipation, resulting in lower chiller coefficient of performance (COP)
  - For a condenser with a design fouling factor of 44 mm^2.K/W, an increment of scale fouling by 50% in the condenser will cause the chiller COP to decline more than 2%

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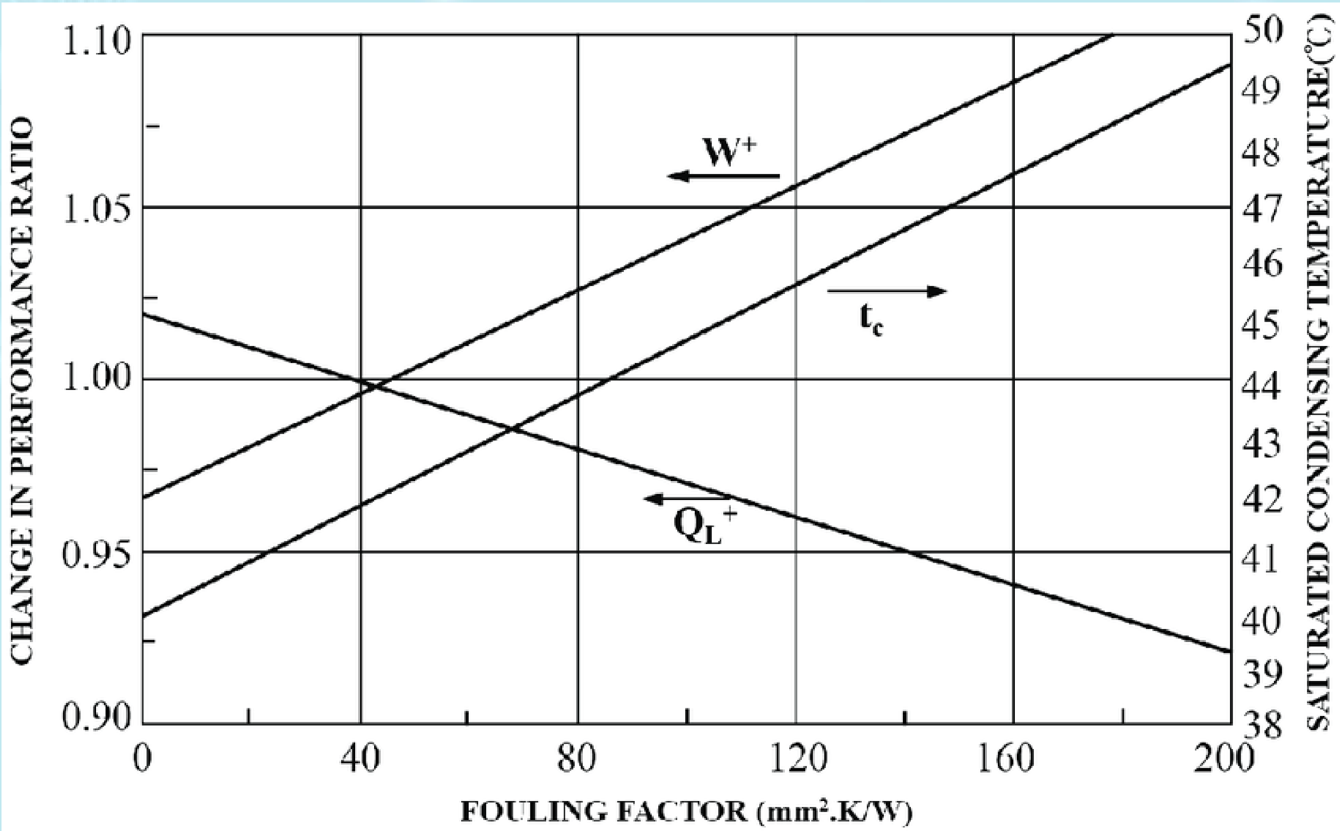
Impact of condenser fouling factor on chiller performance



[Ref: (Stoecker & Jones, 1982)]

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6. Discussions

- Energy impact & operation costs
  - Proper water treatment improves the performance & energy efficiency of the HVAC systems, extends the life of equipment (by controlling scaling, corrosion & fouling which result in equipment damage) while helping to protect human health & safety
  - Optimal energy efficiency & equipment efficiency can be evaluated through operational relations & performance between system equipment
  - Chiller energy consumption & operation costs can be assessed through further research of the ozone MNB system
- In order to develop an effective ozone MNB system, it is essential to examine the bubble characteristics at functional levels & investigate the corresponding system operating parameters to achieve optimization

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7. Conclusions

- MNBs have been increasingly used as a highly efficient & environmentally friendly non-chemical gas-liquid phase process in water treatment
- The ability of the bubbles:
  - Long residence time, high mass transfer efficiency, relatively lower rising velocity, high zeta potential at the interface, easily tailored surface charge, free radical generation ability & improved collusion efficiency
  - Combination of ozone & MNBs has positive synergetic effects on solubility, stability, & gas transfer efficiency
- For fresh water cooling towers in HVAC systems, the ozone MNB technology can provide economic, social & environmental benefits
  - Help to achieve energy saving in buildings & reduce operating costs

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