Effect of micro and nano bubble on biofilm in drinking water distribution systems

Luo Aibao[1], WANG Tianzhi[1,2,*], Luo Peiyuan[1], Zhiwei Zheng[4], Fiallos Manuel[1], Bian Yongning[1,2], Soon-Thiam Khu[1,3]

1. School of Environmental Science & Engineering, Tianjin University, Tianjin 300350, China

2. Tianjin key Laboratory of Pollution Prevention- Control and Carbon Sink along land-sea waters, Tianjin 300350, China

3. Engineering Research Center of City intelligence and Digital Governance, Ministry of Education of the People's Republic of China, Tianjin 300350, China

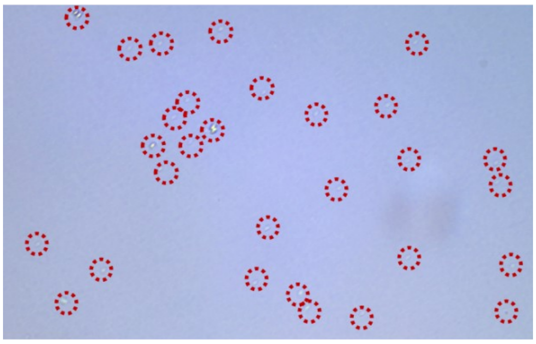
4. College of Water Conservancy Engineering, Tianjin Agricultural University, Tianjin 300392, China

*Corresponding author, E-mail: wangtianzhi@tju.edu.cn

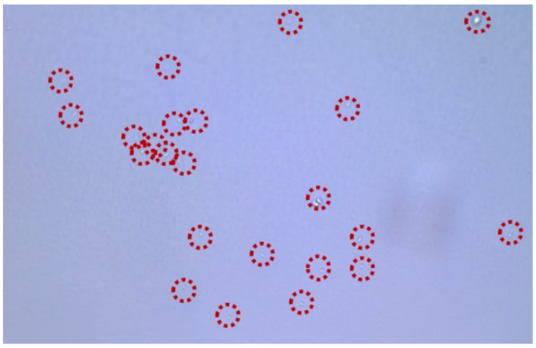
1. Calculation of the bubble concentration in the micro-nanobubbles

$$C = N\frac{S_{Si} \times 1000}{S \times V} \quad (1)$$

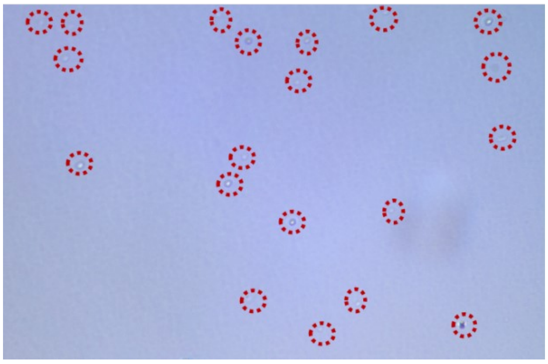
Assuming that the sample is fully laid on a silicon wafer: N denotes the number of micro-nanobubbles observed under the optical microscope; S_{Si} denotes the total area of the observed sample cm^2; S denotes the total area of the actual observation under the objective lens cm^2; V is the volume of micro-nanobubbles water taken uL; C is the concentration of bubbles in the water (pcs/mL).



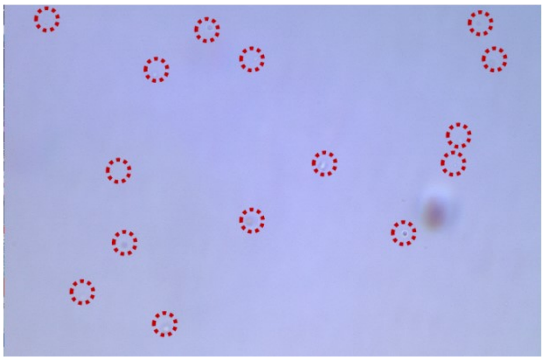
Oxy: 2.42×10^5 MNBs/mL



Air, 1.92×10^5 MNBs/mL



Ozo：1.67x10^5 MNBs/mL



Nit：1.25x10^5 MNBs/mL

2. Fractal dimension calculation method (Posadas A N D,2003)

This paper analyzes and calculates the fractal dimension of biofilm surface structure using the Islet method. The Islet method defines the fractal dimension based on a measurement relationship and can be obtained by the Mandelbrot states [1]. It can be calculated as follows.

$$\alpha_D(\varepsilon) = \frac{L^{\frac{1}{D}}(\varepsilon)}{A^{\frac{1}{2}}(\varepsilon)} \quad (1)$$

Where L is the pore perimeter; A is the pore area; D is the fractal dimension; $\varepsilon = \eta / L_0$, where η is the absolute measurement scale and L_0 is the perimeter of the initial graph; with a fixed scale η, α_D（ε） is a constant, and α_D（ε） is only related to the chosen scale, but not to the size of the graph. Then both sides of the above equation are taken logarithmically to obtain:

$$\log L(\varepsilon) = D\log \alpha_D(\varepsilon) + \frac{D}{2}\log A(\varepsilon) + \frac{D}{2}\log A(\varepsilon) \quad (2)$$

Where C is a constant. The perimeter and area of each pore were measured separately in the electron microscope picture of the biofilm surface structure, and twice the slope obtained from double logarithmic plotting of area and perimeter is the value of the fractal dimension D.

Posadas A N D, Giménez D， Quiroz R， et al．Multifractal characterization of soil pore spatial distributions．Soil Science Society of America Journal．2003，67：1361-1369.

Table S1. Key strains of biofilm microbial communities under different air source conditions obtained by topological analysis

	Domain	Kingdom	Phylum	Class
OTU73	d_Bacteria	k_norank_d_Bacteria	p_Proteobacteria	c_Alphaproteobacteria
OTU147	d_Bacteria	k_norank_d_Bacteria	p_Proteobacteria	c_Alphaproteobacteria
OTU50	d_Bacteria	k_norank_d_Bacteria	p_Bacteroidota	c_Bacteroidia
OTU107	d_Bacteria	k_norank_d_Bacteria	p_Proteobacteria	c_Gammaproteobacteria
OTU632	d_Bacteria	k_norank_d_Bacteria	p_Proteobacteria	c_Gammaproteobacteria
	Order	**Family**	**Genus**	**Species**
OTU73	o_Caulobacterales	f_Hyphomonadaceae	g_SWB02	s_uncultured_bacterium_g_SWB02
OTU147	o_Rhizobiales	f_Hyphomicrobiaceae	g_Hyphomicrobium	s_unclassified_g_Hyphomicrobium
OTU50	o_Chitinophagales	f_Chitinophagaceae	g_Terrimonas	s_unclassified_g_Terrimonas
OTU107	o_Pseudomonadales	f_Moraxellaceae	g_Acinetobacter	s_Acinetobacter_lwoffii
OTU632	o_Burkholderiales	f_Rhodocyclaceae	g_Sulfuritalea	s_uncultured_bacterium_g_Sulfuritalea

Table S2. Throughput analysis of different gas sources for the regulation of biofilm growth at different growth stages

GP

X	→	Y	Non-standardized coefficient	Standardized coefficient	S.E.	C.R.	P
·OH	→	NTU	-0.009	-0.63	0.005	-1.815	0.069*
Size	→	P	0	-0.671	0	-2.025	0.043**
NTU	→	TOC	-3.536	-0.889	0.814	-4.342	0.000***
TOC	→	PS	0.264	1	0.038	6.943	0.000***
Zeta	→	PS	0.005	0.334	0.002	2.319	0.020**
P	→	D	0.449	0.911	0.091	4.935	0.000***
PS	→	DW	-2.48	-0.618	1.411	-1.758	0.079*

MP

X	→	Y	Non-standardized coefficient	Standardized coefficient	S.E.	C.R.	P
·OH	→	TOC	-3.778	-1.481	0.479	-7.881	0.000***
Ace	→	TOC	-0.335	-0.929	0.068	-4.942	0.000***
·OH	→	Ace	-5.47	-0.773	2.007	-2.726	0.006***
Chaos	→	PS	-1.49	-0.814	0.332	-4.484	0.000***
Ace	→	PS	-0.001	-0.635	0	-3.497	0.000***
TOC	→	EC	4.896	0.834	1.447	3.383	0.001***
PS	→	DW	-17.332	-0.649	9.084	-1.908	0.056*
Zeta	→	P	0.005	0.936	0.001	5.927	0.000***
Size	→	NTU	0.001	0.738	0	2.449	0.014**

SP

X	→	Y	Non-standardized coefficient	Standardized coefficient	S.E.	C.R.	P
·OH	→	TOC	-3.246	-0.767	1.216	-2.67	0.008***
·OH	→	Chaos	-0.004	-0.632	0.002	-1.824	0.068*
Chaos	→	PN	-1.023	-0.023	20.318	-0.05	0.960
·OH	→	Ace	11.111	0.779	4.002	2.776	0.005***
·OH	→	D	0.003	0.446	0.003	1.113	0.266
Chaos	→	PS	-1.635	-0.829	0.494	-3.314	0.001***
PN	→	DW	1.599	0.941	0.258	6.206	0.000***
TOC	→	NTU	-0.024	-0.952	0.003	-6.943	0.000***

Note: ***, **, and * represent 1%, 5%, and 10% significance levels, respectively.

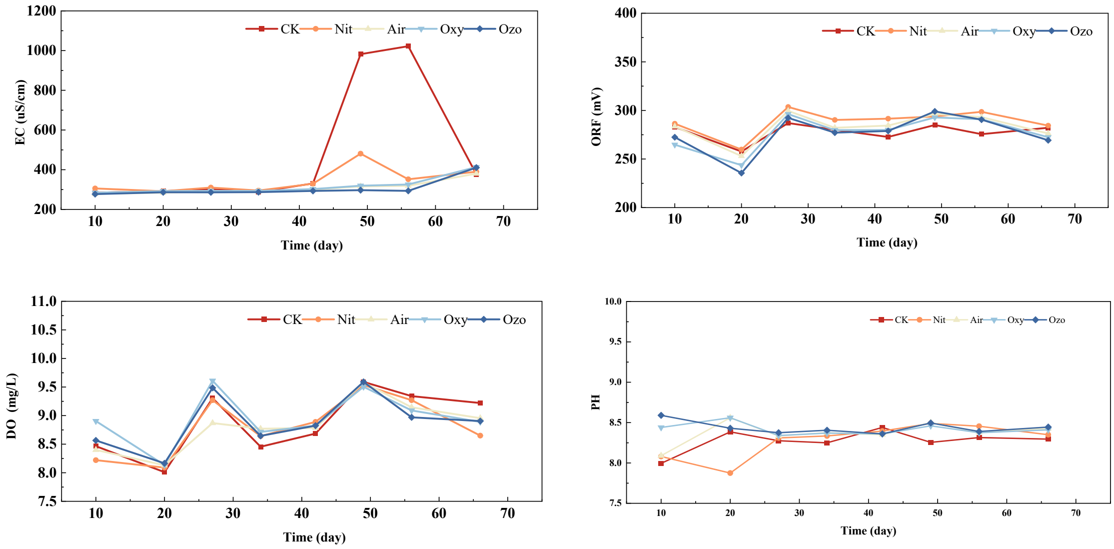


Figure S1. Water quality changes under different gas conditions.

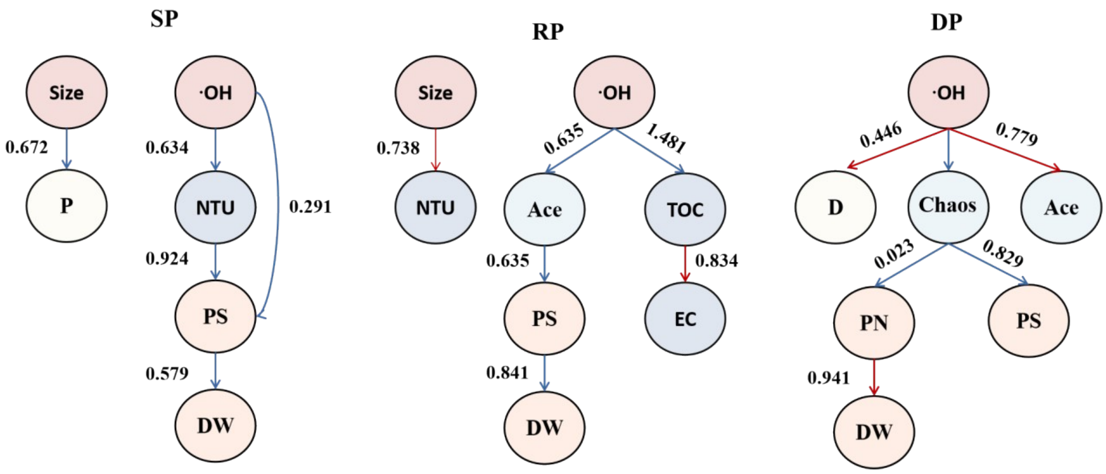


Figure S2. Micro/Nanobubble Biofilm Control Pathway

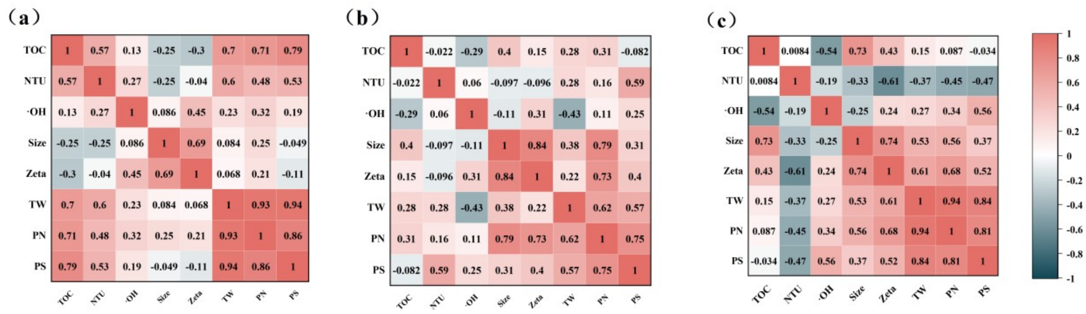


Figure S3. Correlation analysis of water quality-related indexes under micro-nano bubble treatment at different stages. (a) SP (b) RP (c) DP.