Online monitoring of *N*-nitrosodimethylamine for the removal assurance of 1,4-dioxane and other trace organic compounds by reverse osmosis

Takahiro Fujioka[1,*], Hitoshi Kodamatani[2], Haruka Takeuchi[3],

Hiroaki Tanaka[3], Long D. Nghiem[4]

[1]*Water and Environmental Engineering, Graduate School of Engineering, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan*

[2]*Division of Earth and Environmental Science, Graduate School of Science and Engineering, Kagoshima University, Kagoshima 890-0065, Japan*

[3]*Research Center for Environmental Quality Management, Kyoto University, 1-2 Yumihama, Otsu, 520-0811, Japan*

[4]*Centre for Technology in Water and Wastewater, University of Technology Sydney, Ultimo NSW 2007, Australia*

Supplementary Information

* Corresponding author: Takahiro Fujioka, Email: tfujioka@nagasaki-u.ac.jp, Ph +81 095 819 2695

Table S1 – Physicochemical characteristics of the selected TOrCs.

Compound	Structure	MW [Da]	Minimum projection area* [Å^2]	Log *D* at pH 6.5*	pK_a*	Ionisation at pH 6.5* [%]	Supplier **
Neutral & hydrophilic							
N-nitrosodimethylamine	$C_2H_6N_2O$	74.08	20.10	0.04	3.52	0	US
1,4-dioxane	$C_4H_8O_2$	88.10	18.80	-0.09	-	0	WA
N-nitrosomethyelthylamine	$C_3H_8N_2O$	88.11	22.03	0.40	3.42	0	US
N-nitrosopyrrolidine	$C_4H_8N_2O$	100.12	25.04	0.44	3.30	0	US
N-nitrosomorpholine	$C_4H_8N_2O_2$	116.12	26.92	-0.18	3.14	0	US
Acetaminophen	$C_8H_9NO_2$	151.17	21.75	0.91	9.46	0	WA
Theophyline	$C_7H_8N_4O_2$	180.17	28.75	-0.79	7.82, -0.78	5	WA
Antipyrine	$C_{11}H_{12}N_2O$	188.23	32.41	1.22	0.49	0	WA
Caffeine	$C_8H_{10}N_4O_2$	194.19	30.01	-0.55	-1.16	0	WA
Primidone	$C_{12}H_{14}N_2O_2$	218.26	40.90	1.12	11.5	0	WA
Sulfathiazole	$C_9H_9N_3O_2S_2$	255.31	41.22	0.86	6.93, 2.04	27	WA
Cyclophosphamide	$C_7H_{15}Cl_2N_2O_2P$	261.08	45.84	0.10	13.43, 0.08	0	WA
Sulfamerazine	$C_{11}H_{12}N_4O_2S$	264.30	47.43	0.41	6.99, 2	24	WA
Sulfadimidine	$C_{12}H_{14}N_4O_2S$	278.33	48.80	0.54	6.99, 2	24	WA
Sulfamonomethoxine	$C_{11}H_{12}N_4O_3S$	280.30	47.18	0.66	7.15, 2.63	18	WA
Sulfadimethoxine	$C_{12}H_{14}N_4O_4S$	310.33	49.84	1.14	6.91, 1.95	28	WA
Thiamphenicol	$C_{12}H_{15}Cl_2NO_5S$	356.21	49.34	-0.22	8.75	1	WA
Neutral & hydrophobic							
Crotamiton	$C_{13}H_{17}NO$	203.29	40.23	3.09	-0.60	0	LKT
Isopropylantipyrine	$C_{14}H_{18}N_2O$	230.31	40.75	2.35	0.87	0	WA
Triclosan	$C_{12}H_7Cl_3O_2$	289.54	40.00	4.95	7.68	6	WA
Triclocarban	$C_{13}H_9Cl_3N_2O$	315.58	49.11	4.93	11.42	0	SA
Griseofulvin	$C_{17}H_{17}ClO_6$	352.77	54.74	2.17	-	0	MP
Positively charged							
Ethenzamide	$C_9H_{11}NO_2$	165.19	29.99	1.53	6.2, 7.9	51	WA
Salbutamol	$C_{13}H_{21}NO_3$	239.32	41.28	-2.01	9.4, 10.12	100	WA
Propranolol	$C_{16}H_{21}NO_2$	259.35	42.47	-0.32	9.67, 14.09	100	WA
Atenolol	$C_{14}H_{22}N_2O_3$	266.34	36.85	-2.48	9.68, 14.07	100	WA
Trimethoprim	$C_{14}H_{18}N_4O_3$	290.32	51.14	0.60	7.16	82	WA
Disopyramide	$C_{21}H_{29}N_3O$	339.48	79.36	0.11	10.42	100	WA
Sulpiride	$C_{15}H_{23}N_3O_4S$	341.43	55.95	-1.55	8.39, 10.24	99	WA
Pirenzepine	$C_{19}H_{21}N_5O_2$	351.41	66.19	0.19	7.2, 14.78	82	WA
Diltiazem	$C_{22}H_{26}N_2O_4S$	414.52	62.99	1.05	8.18. 12.86	98	WA
Tiamulin	$C_{28}H_{47}NO_4S$	493.75	75.23	1.61	9.51, 14.43	100	WA
Clarithromycin	$C_{38}H_{69}NO_{13}$	747.97	106.52	1.36	8.38, 12.46	99	WA
Azithromycin	$C_{38}H_{72}N_2O_{12}$	749.00	116.57	-2.89	9.57, 12.43	100	LKT
Roxithromycin	$C_{41}H_{76}N_2O_{15}$	837.06	126.79	0.47	9.08, 12.45	100	WA
Tylosin	$C_{46}H_{77}NO_{17}$	916.11	120.92	1.54	7.2, 12.45	83	WA
Negatively charged							
Clofibric acid	$C_{10}H_{11}ClO_3$	214.65	30.34	-0.08	3.37	100	AA
Naproxen	$C_{14}H_{14}O_3$	230.26	34.77	0.70	4.19	100	WA
Nalidixic acid	$C_{12}H_{12}N_2O_3$	232.24	34.30	0.33	4.66, 5.77	84	WA
Mefenamic acid	$C_{15}H_{15}NO_2$	241.29	37.30	2.83	3.89, -1.58	100	WA
Fenoprofen	$C_{15}H_{14}O_3$	242.27	40.56	1.15	3.96	100	LKT
Sulfapyridine	$C_{11}H_{11}N_3O_2S$	249.29	44.58	0.64	6.24, 2.13	65	WA
Sulfamethoxazole	$C_{10}H_{11}N_3O_3S$	253.28	46.11	0.38	6.16, 1.97	69	WA
Ketoprofen	$C_{16}H_{14}O_3$	254.29	41.68	1.05	3.88	100	WA
Levofloxacin	$C_{18}H_{20}FN_3O_4$	361.37	45.74	0.27	5.29, 6.16	67	LKT
Bezafibrate	$C_{19}H_{20}ClNO_4$	361.82	40.35	1.37	3.83, -0.84	100	LKT
Lincomycin	$C_{18}H_{34}N_2O_6S$	406.54	61.56	-1.80	7.97, 12.37	97	MP
Zwitterion							
Norfloxacin	$C_{16}H_{18}FN_3O_3$	319.34	42.78	-0.98	5.58, 8.68	89	WA
Ciprofloxacin	$C_{17}H_{18}FN_3O_3$	331.35	42.99	-0.87	5.56, 8.68	89	LKT
Enrofloxacin	$C_{19}H_{22}FN_3O_3$	359.40	50.07	0.96	5.52, 6.66	96	ICN
Tetracycline	$C_{22}H_{24}N_2O_8$	444.44	62.32	-3.50	8.19, 2.92	97	WA

*Chemical properties: The information was obtained from ChemAxon (https://www.chemaxon.com/).

**Suppliers: SA (Sigma-Aldrich Japan, Tokyo, Japan); US (Ultra Scientific, Kingstown, RI, USA); WK (Wako Pure Chemical Industries, Osaka, Japan); LKT (LKT Laboratories, St Paul, MN, USA); AA (Alfa Aesar, Ward Hill, MA, USA); ICN (ICN Biomedicals, Irvine, CA, USA); MP (MP Biomedicals, Santa Ana, CA, USA).

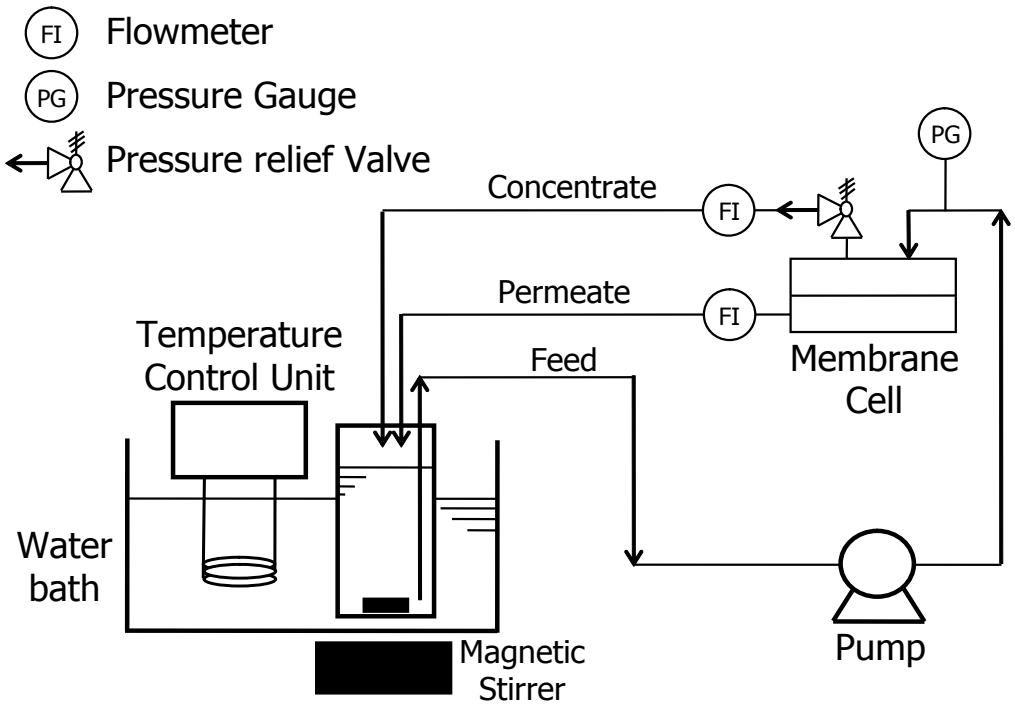

Fig. S1 – Schematic diagram of the cross-flow RO treatment system. A bench-scale RO treatment system was comprised of a stainless steel membrane cell (Iwai Pharma Tech, Tokyo, Japan), high-pressure pump (KP-12, FLOM, Tokyo, Japan), 2-L glass reservoir with a stainless steel heat exchanging coil connected to a temperature control unit (NCB-500, Tokyo Rikakikai, Tokyo, Japan). The membrane cell held a circular flat-sheet membrane coupon with effective surface area of 36.3 cm^2.

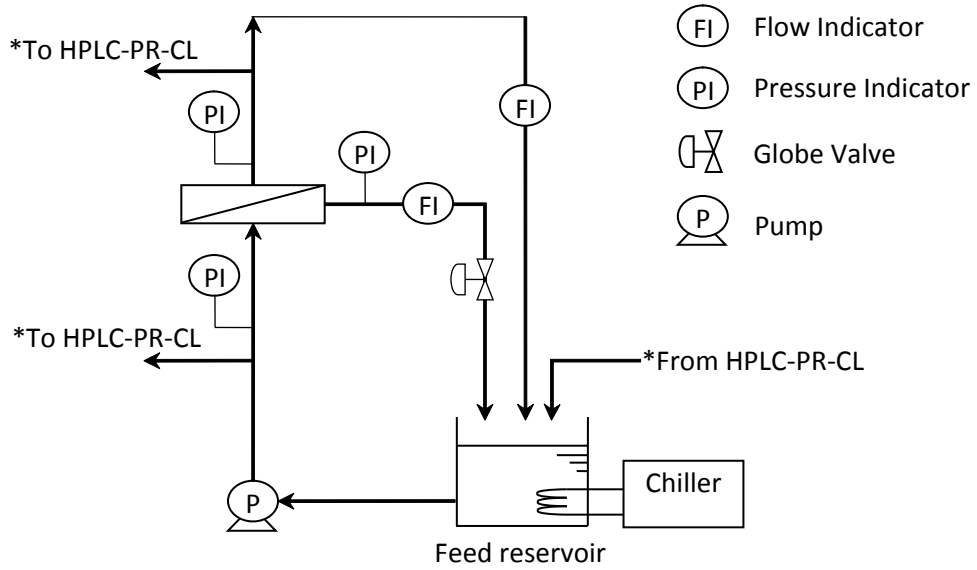

Fig. S2 – Schematic diagram of the pilot-scale RO treatment system. The system comprised of a 4-in. glass-fibre pressure vessel (ROPV, Nangang, China), 65-L stainless steel reservoir, a high-pressure pump (25NED15Z, Nikuni Co., Ltd., Kawasaki, Japan), digital flow meters (FDM, Keyence Co., Osaka, Japan), digital pressure indicators (GPM, Keyence Co., Osaka, Japan), a pressure gauge, stainless steel pipes in the feed stream and PVC pipes and PTFE tubing in the permeate stream). The membrane element was rinsed with pure water to eliminate residual preservatives on the RO element. Feed solution temperature was maintained in the reservoir using a titanium heat exchanging pipe connected to a chiller unit (CA-1116A, Tokyo Rikakikai Co. Ltd., Tokyo, Japan).

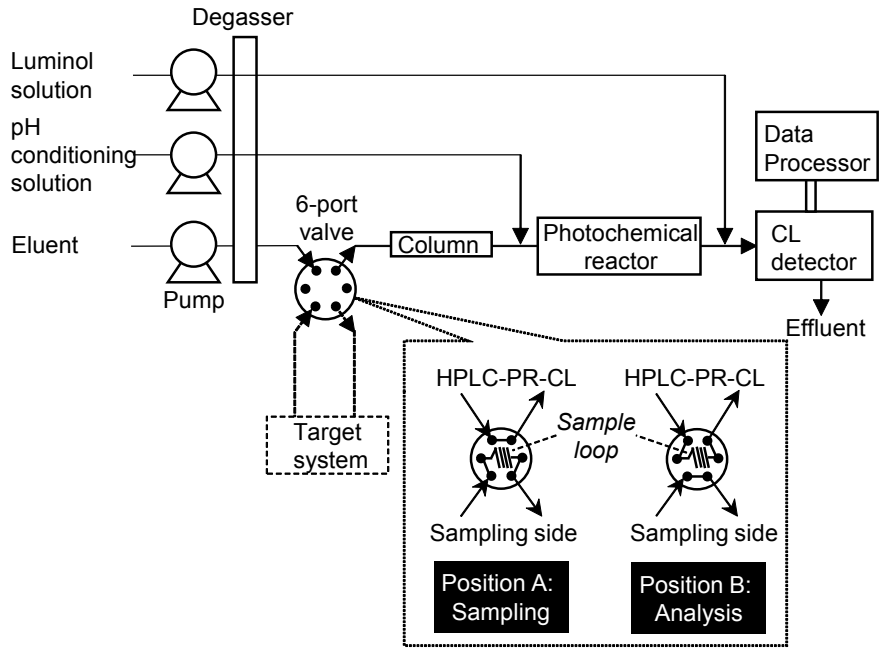

Fig. S3 – Schematic diagram of the online HPLC-PR-CL instrument with a 6-port valve. The online HPLC-PR-CL monitor was assembled with commercially available components: DGU-20A_3 degasser (Shimadzu), six-port valve (HV-2080-01, JASCO, Tokyo, Japan), valve controller (Nichiri Mfg. Co. Ltd., Chiba, Japan), CTO-20AC column oven (40 °C), InertSustain C18-AQ column (5 µm, 4.6 mm i.d., 250 mm GLsciences, Tokyo, Japan), CL-2027 chemiluminescence detector (JASCO, Tokyo, Japan), and Chromato-PRO data processor (Runtime Instruments, Kanagawa, Japan). In addition, a low-pressure mercury lamp (15 W, CL-15, Panasonic, Tokyo, Japan) was used to construct the photochemical reactor. Eluent solution (10 mM phosphate buffer with 5% methanol) was fed to the instrument in isocratic mode at a flow rate of 1.5 mL/min.

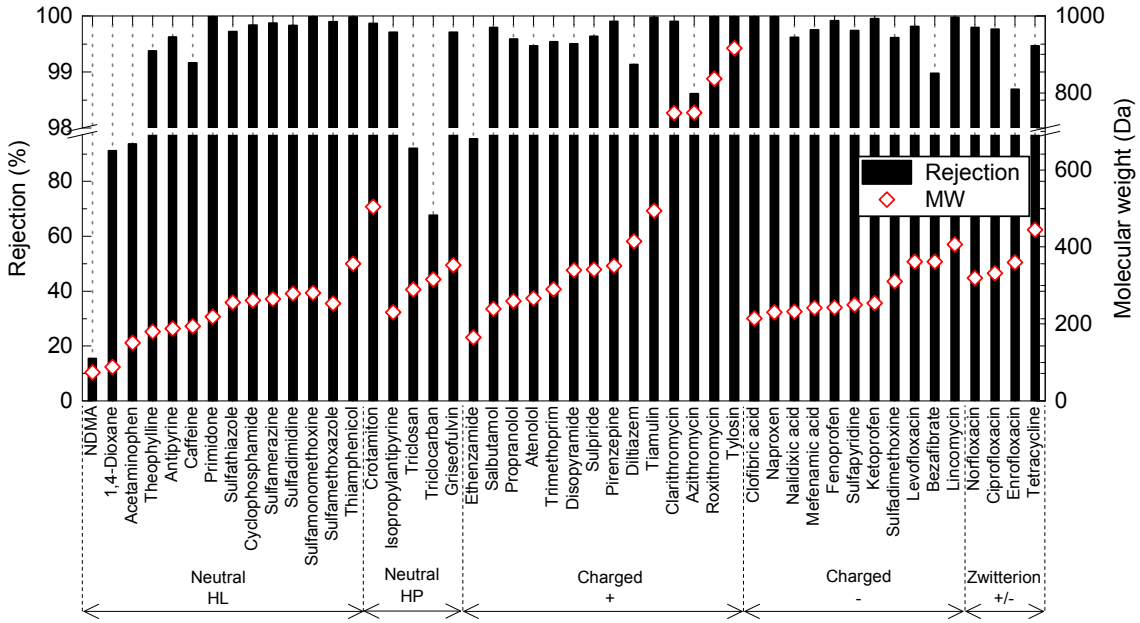

Fig. S4 – Rejection of TOrCs by ESPA2 RO membrane at the pilot scale (permeate flux = 20 L/m^{2}h, feed temperature = 20–22ºC).

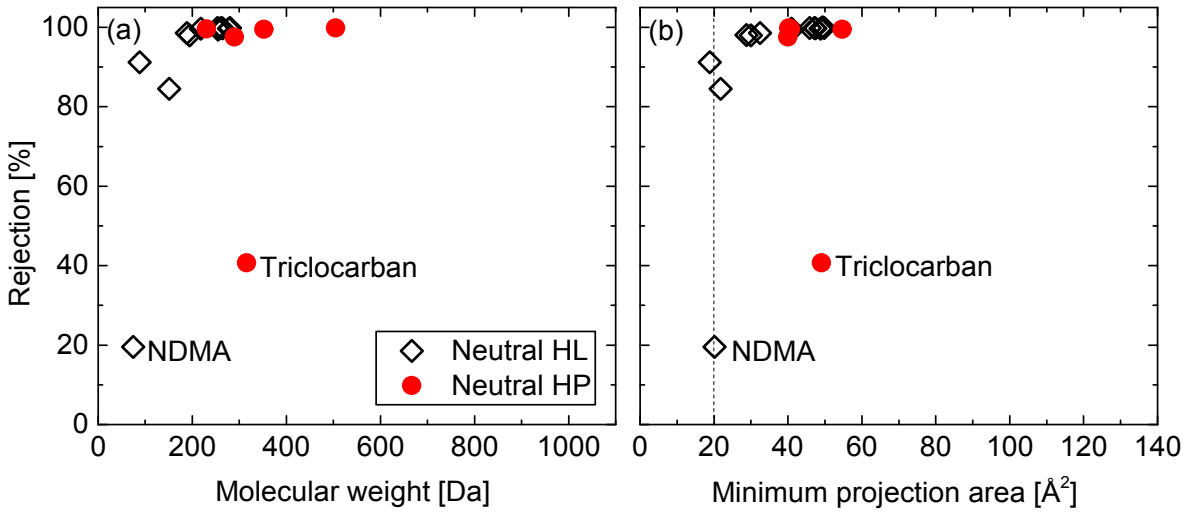

Fig. S5 – Rejection of NDMA, 1,4-dioxane and 17 neutral TOrCs by ESPA2 RO membrane as a function of their (a) molecular weight and (b) minimum projection area at the pilot scale treatment of UF-treated wastewater (permeate flux = 20 L/m²h, feed temperature = 29–30 ºC).

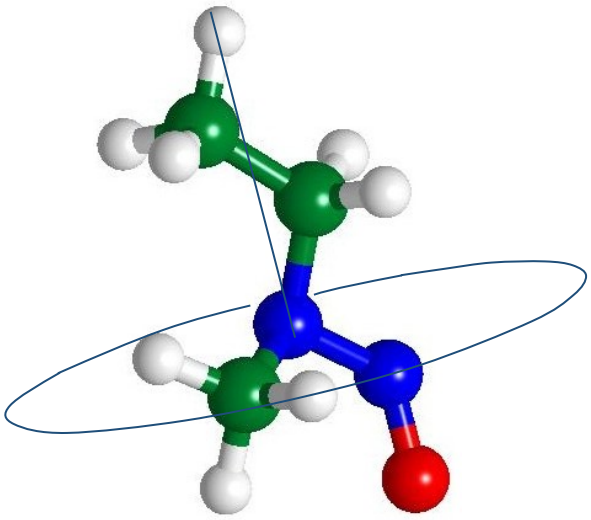

Fig. S6 – Schematic figure of minimum projection area of NMEA. The line perpendicular to the circular disk represents the center axis of the minimum projection area. Minimum projection area is calculated based on the van der Waals radius after the molecular orientation for the projection is fine-tuned by a numerical optimizer (projection optimization).

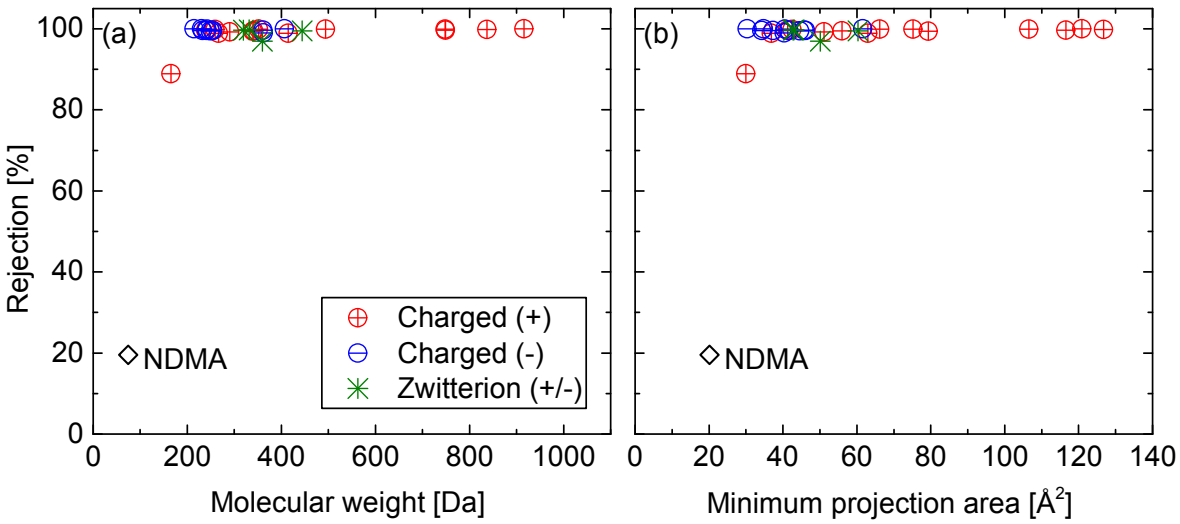

Fig. S7 – Rejection of NDMA and 29 charged TOrCs by ESPA2 RO membrane as a function of their (a) molecular weight and (b) minimum projection area at the pilot scale treatment of UF-treated wastewater (permeate flux = 20 L/m^{2}h, feed temperature = 29–30 ºC).