RECLAIMED WASTEWATER FACILITY USING OZONE AND CERAMIC MEMBRANES

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Abstract

In urban regions where water demands are high and water resources limited, the reuse of treated sewage water is a viable alternative in Japan. Bureau of Sewerage Tokyo Metropolitan Government (BSTMG) started applying such reuse program since 1984 and has to-date supplied approximately 2.1 billion gallon per year of reclaimed water for flushing, washing and irrigation. To expand capacity, enhance efficiency, and space-saving, reclaimed wastewater systems/technologies development are required.

BSTMG introduced a new reclaimed water project in Shibaura Water Reclamation Center (wastewater treatment plant) consisting of the following processes: 1) biological treatment, 2) an oxidation process using ozone, 3) a coagulation process, and 4) ceramic MF membrane (0.1μm) filtration. Plant capacity is 7,000 m^3/day (1.85 MGD). It has achieved trouble-free operation for more than two years since start up in April 2010.

Metawater ceramic membrane microfiltration system with an operational flux of 4.2 m^3/m^2/day (100 gfd) to 5.6 m^3/m^2/day (137 gfd) has demonstrated stable operation for more than 9 months period without CIP. Ceramic membrane can periodically be washed by ozonated water (of 0.1 mg O_3/L of dissolved ozone) at the ceramic membrane inlet to enhance overall performance. Long-term operation at the Shibaura facility produced epidemiologically safe water: Turbidity of <0.2 NTU, low color of 0 to 3, excellent removal of bacteria, Escherichia coli, and virus. Filtrate quality during initial pilot study met all Tokyo and current California's reclaimed water standards.

Introduction

Even in regions such as North and Central America, North Africa, Middle East, India, China, Australia, water shortages exist, reclaimed wastewater can be a secondary source of water which can be tapped for major cities.

Water shortage is a growing concern in Japan urban areas. In recent years, reclaimed water from municipal wastewater treatment plants has gradually becoming an important water resource especially in densely populated areas. The development of membrane technology for wastewater reuse has been one of the focuses. Utilizing developed ceramic membrane and ozonation technologies, Metawater has been able to produce filtrate to meet increasing such water demands.

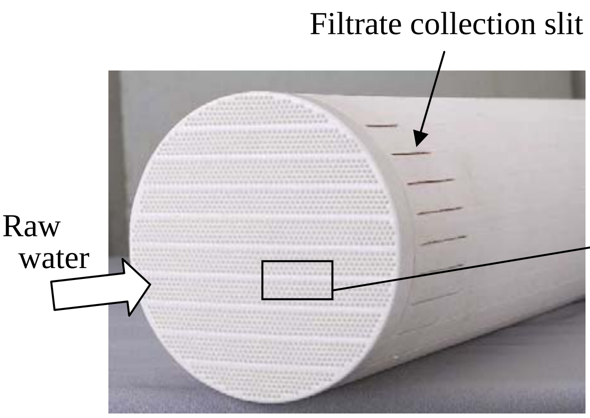
Under the collaboration effort between METAWATER and Bureau of Sewerage Tokyo Metropolitan Government for system development and Tokyo Metropolitan Sewerage Service Corporation for maintenance management, on site pilot testing began from 2006 to 2009 to verify design parameters. In April 2010 full scale plant started up followed by operational optimization.

Ceramic membrane

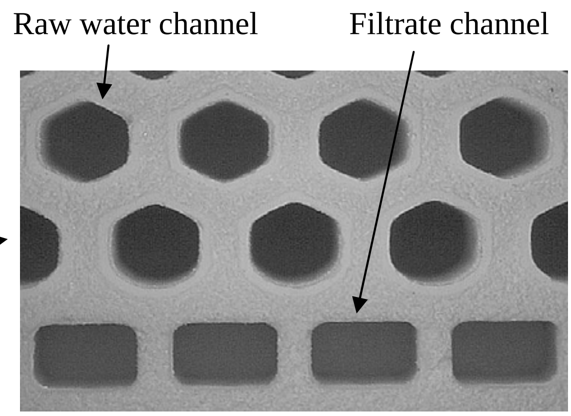
Ceramic membrane element used has the dimension of 180mm outer diameter (O.D.) and 1.5 m in length with surface area of 25 m^2 (269sqft) per element, with s 0.1 micron nominal pore size. Photo of a ceramic membrane element is shown in Figure 1.

Table 1. Specification of the ceramic membrane

Nominal pore size	0.1 micron
Dimension	180 mm O.D. x 1.5 m L
Membrane surface area	269sqf (25m^2)



a) External appearance of a ceramic membrane element



b) Internal Channel structure

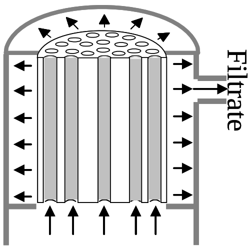
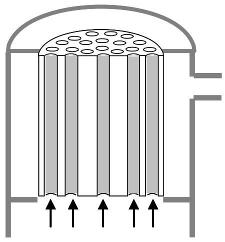
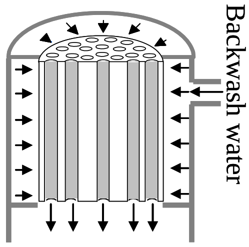
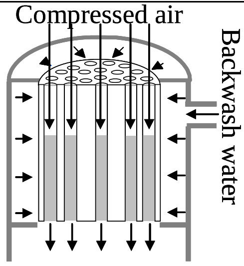
Figure 1. Ceramic membrane elemental structure

Raw water flows into multiple water channels within the ceramic membrane element and ceramic membrane 0.1 micron surface layer effects microfiltration. Filtrated water is collected in the filtrate channels and flows out from multiple filtrate collection slits.

Ceramic membrane operation

Figure 2 depicts a typical ceramic membrane operation cycle. Each cycle consists of two steps; filtration process and backwashing process. Metawater ceramic membrane filtration is a dead-end filtration process. Backwashing is conducted every 1-2 hours dependent on raw water quality and flow rate. Backwashing process consists of two steps; reverse flow by filtrate followed by air flashing.

Fig. 2. Filtration and backwash process

	Filtration process	Backwash process		
		CEB	Reverse flow	Air flushing
Schematic diagram	 Raw water	 NaClO or H_2SO_4	 Wastewater	 Wastewater
Operation mode	Dead-end filtration	Soaking with NaClO or H_2SO_4	Backwash by filtrate	Discharged by air blow
Pressure	– 20psi	–	Max. 70psi	Max. 30psi
Duration	1 – 2 hr	2 – 5 min	2 – 20 seconds	2-5 seconds

Chemical cleaning

Two types of membrane chemical cleaning are conducted periodically.

a. Chemical Enhanced Backwash (CEB):

CEB is the method for soaking ceramic membrane elements in a relatively low concentrated chemical solution for a short period of time (5-30 minutes) to remove foulants from membrane surfaces. CEB conducted once in a daily or weekly dependent on raw water quality. CEB soaking process is conducted prior to backwashing cycle. Sodium hypochlorite (NaOCl) or sulfuric acid (H_2SO_4) was used for CEB, NaOCl for biofouling prevention (bacterial growth), H_2SO_4 for inorganic fouling control.

b. Clean in Place (CIP):

CIP immerses ceramic membrane elements in a high concentrated chemical solution for an extended period of time (4-16 hours) to remove membrane foulants to the maximum extent.

System and methods

Pilot testing

Shibaura site pilot testing was conducted from 2006 to 2009. Flow diagram of the reclaimed wastewater facility is shown in Figure 2. This new system consists of the following processes: 1) biological treatment, 2) an oxidation process using ozone, 3) a coagulation process, and 4) a ceramic MF membrane (0.1 μm) filtration. A part of the secondary effluent from the final sedimentation tank was used as raw water, into which ozone is dosed. This process provided additional microcoagulation/flocculation for downstream processes.

During the coagulation process, small particles in the raw water are combined (coagulated) into larger aggregates. With coagulation, good quality filtrate can be produced utilzing the ceramic membrane filtration process.

When nitrite is present in raw water, a biofilter (biological treatment), in addition to solid removal was installed prior to the ozone contact tower. (Nitrite consumes ozone.)

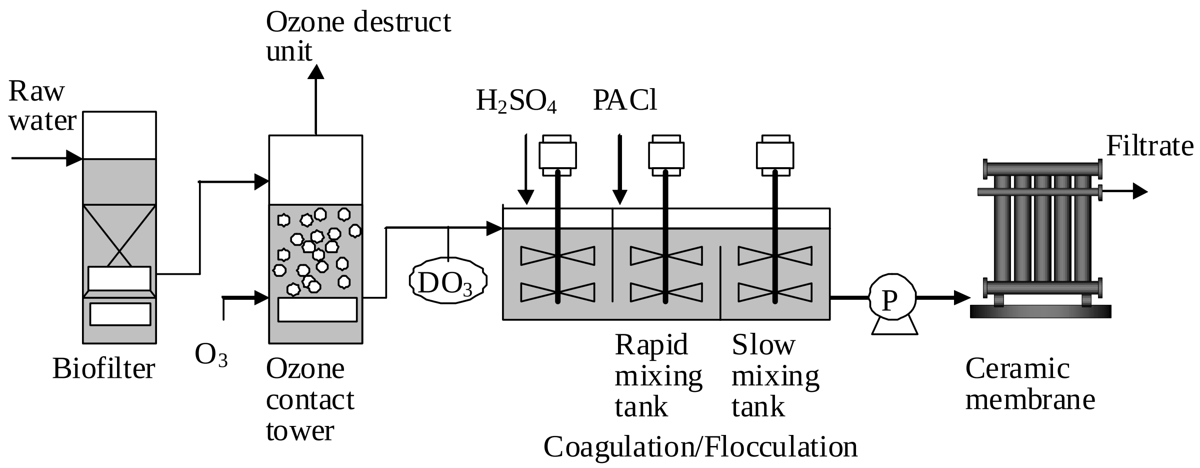


Figure 2. The flow diagram of the reclaimed wastewater facility

System characteristics

The Shibaura system has two unique features; one is the use of ozonation and the other in the utilizing ceramic membrane.

Ozonation greatly enhances coagulation / flocculation performance by “reforming” the surface characteristics of small particles in raw water. An added small amount of ozone is assumed to change the surface characteristics of small particles in raw water. Stable filtration can be achieved as particles which potentially could lead to membrane fouling are coagulated & reduced.
Various organics inclusive of molecules responsible for odor could also be removed by ozonation.

Dissolved organic matter (DOM) at the Shibaura reclaimed wastewater facility was studied by Komatsu et al. They divided DOM into five fractions: hydrophobic acids (AHS), hydrophobic neutrals (HoN), hydrophilic acids (HiA), bases (BaS), and hydrophilic neutrals (HiN). AHS concentration and ratio of AHS to total DOM were observed to be significantly decreased and HiA concentration greatly increased at the ozone contact tower. HiA is selectively removed by coagulation. It is indicated that the characteristics of DOM were substantially altered by HiA ozonation resulted in easy removal by coagulation.

Study confirmed a positive effect of ozone and coagulant for stable membrane filtration from on-site testing conducted by using ceramic membrane filtering secondary effluent. The effectiveness of ozonation prior to coagulation was proven to achieve the stable membrane filtration (Noguchi et al., 2007). More favorable and stable operation can be achieved using PACl for coagulation. Trans Membrane Pressure (TMP) rate was reduced tenfold (when compared to operation with no coagulation. (Noguchi et al., 2007)

Ceramic membrane (unlike conventional polymeric membrane) possesses high chemical resistance to ozone and has high structural resistance to (high pressure) backwashing. Ceramic membrane filtration system permits a significant increase in design flux rate. "Fiber breakage" during is unlikely to occur. This no-fiber breakage has been demonstrated by METAWATER over 13+ years of operation experience. In conjunction with ozonation and coagulation processes, benefits of ceramic membrane filtration are multifold: long membrane life, minimal loss in permeability, excellent water quality and low life cycle cost.

Ceramic membrane selected for this plant is 0.1 micron in pore size. Bacteria and cryptosporidium are removed. Viruses can also be sufficiently removed by the cake layer formed on the membrane surface (Takemura et al., 2003). Dead end filtration is selected due to high water recovery rate, targeted more than 98%, with low energy requirement.

Membrane filtration stability by controlling dissolved ozone concentration

Ozone dosage is dependent on raw water quality and dosages will affect the degree of microfloculation/coagulation. Ozone dosage should be controlled to avoid over dosing. Monitoring and control ozone dosage utilizing dissolved ozone concentration is an effective control scheme. Lower operating cost and stable membrane filtration can be achieved with the monitoring of TMP rate and ozone consumption. (Noguchi et. al, to be published)

Full scale system operation

Shibaura reclaimed wastewater facility

Shibaura reclaimed wastewater facility was installed at the Shibaura Water Reclamation Center (municipal wastewater treatment plant) in Tokyo (Refer to Table 3 for plant details). Plant capacity is 7,000m^3/day (1.85MGD) and it has been operating continuously and stably since April 2010.

Table 3. General description of the Shibaura reclaimed wastewater facility

Biofilter	4.5m O.D. x 5.9mH x 4tanks
	Biofilter media / Anthracite
Ozonizer	Oxygen Source Type
	2.5kgO_3/hr (133ppd)x 2 ozonizers
Ceramic membrane	108 elements 9elements x 6modules x 2trains

Nitrite in raw water is detected occasionally as a result of secondary treatment. To remove nitrite, four biofilter tanks were installed prior to the ozone contactor. Two vertical ozone contact towers are used for the pre-ozonation process. Dissolved ozone concentration is measured at outlet pipe of ozone contact tower. As indicated earlier, ozone dosage is controlled via dissolved ozone concentration feedback.

Coagulation/flocculation process is composed of 3 tanks with impeller type mixer, a pH control tank, a rapid mixing tank and a slow mixing tank. Rapid mixing tank detention time was 2minutes. Slow mixing tank detention time was 2 minutes.

Results and discussion

Suitable operating condition for stable filtrating operation

Full scale operation started in April 2010. Operation parameter has since been adjusted for optimal operation. (refer to Table 4). Dissolved ozone concentration control range was changed from 0.1 to 0.5mgO_3/L. Ceramic membrane filtration was stable at 0.3 and 0.5mgO_3/L. When dissolved ozone concentration is below 0.1mgO_3/L, an increase in TMP was observed. Optimal dissolved ozone concentration was set at 0.3 mgO_3/L.

pH range was at 6.3 to 6.8. Ceramic membrane filtration was independent of pH, but most desirable 6.8.

Coagulant (PACl) dosage range was 20 to 68 mg PACl/L. Ceramic membrane filtration operated stable between 50 to 68 mg PACl/L. At PACl/L level between 20 to 40mg, an increase in TMP was observe.

Operational flux of ceramic membrane range was 2.8 to 5.6 m^3/m^2/day (69 – 137gfd). When 6, 5, 4 and 3 modules were operated, operational flux was 2.8, 3.3, 4.2 and 5.6 m^2/day respectively. Ceramic membrane filtration operation was found to operate stably at 2.8 to 4.2m^3/m^2/day (69 – 103gfd). An increase in TMP was observed at 5.6m^3/m^2/day (137gfd). Operational flux was optimized at 4.2 m^3/m^2/day (103 gfd).

Backwash interval range was 1.0 to 2.5 hours. Ceramic membrane filtration operation operated stably at 1.0 to 2.0 hours intervals. An increase in TMP was observed if backwash is set > 2.5 hours. Backwash interval was optimized at 2.0 hours.

Table 4. Operating condition

Raw water		2nd effluent of municipal treatment plant
Biofilter	Filtration rate	120 m^3/m^2/day
Ozonation	Controlling dissolved ozone concentration	0.1 – 0.5 mgO_3/L
	Ozone contact tower HRT	10 min.
Coagulation	pH adjustment	6.3 – 6.8
	PACl dosage	20 – 68 mgPACl/L
Ceramic membrane	Flux	2.8 – 5.6 m^3/m^2/day (69 – 137 gfd)
	Backwash interval	1.0 – 2.5 hr

Stable ceramic membrane filtrating operation

Figure 3 summarizes Shibaura operation results. Initial TMP, adjusted to 25 deg C was taken immediately after backwash. Interval of acid CEB was 2 to 3 times per week. NaClO CEB was conducted once a week prior to June 2011. Post July 2011, facility operated with no NaClO CEB. CIP was conducted in May 2010 and September 2011.

Two reasons contributing to TMP increase in the early stage: (i) biofouling of ceramic membrane filtrate (ii) non optimized operating condition.

Biofouling was attributed to bacteria growth in the filtrate tank. Initial ceramic membrane backwash utilized filtrate from the filtrate tank and bacteria growth was the primary cause for biofouling. Biofouling was prevented with periodic washing of the filtrate tank with NaClO.

Non optimized operation condition was primary due to the lack of appropriate dissolved ozone dosage control and low PACl.

Upon the elimination of biofouling and upon the implementation of ozone dosage and PAC1 control, TMP decreases.

Continuous long term stable filtration operation (Figure 3) was achieved and confirmed at operational flux rate between 4.2 to 5.6 m^3/m^2/day (103 – 137 gfd) from October 2010 to June 2011. Long term stable membrane filtration could be achieved via operation without CIP for over 9 months.

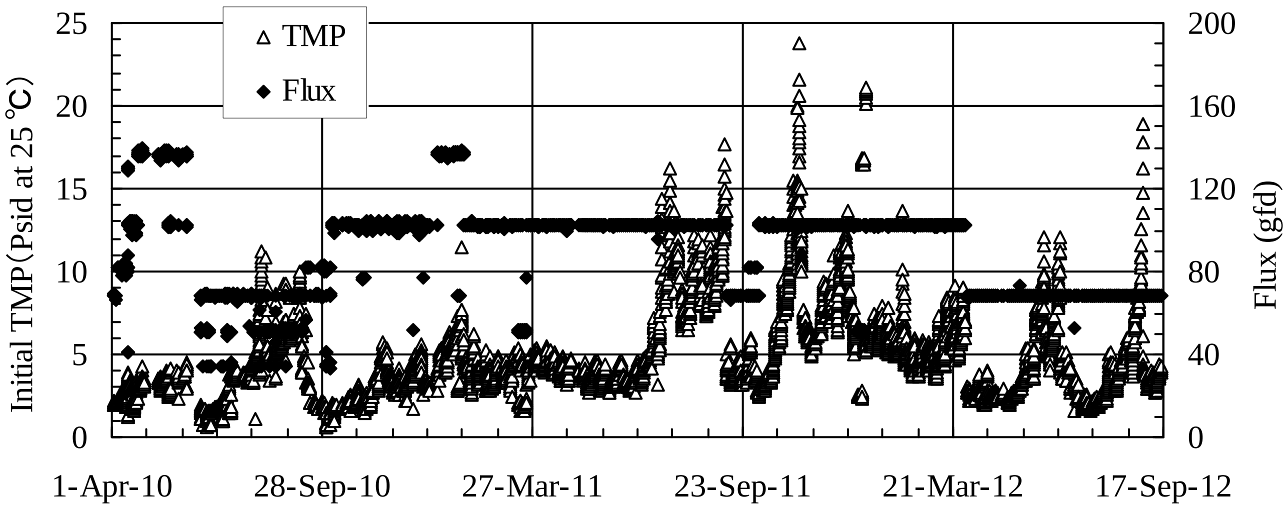


Figure 3. Operational result of ceramic membrane filtration

Ceramic Membrane cleaning by dissolved ozone

Ozone injection rate distribution for three controlling dissolved ozone concentration is shown in Figure 4. Raw water quality fluctuated daily and weekly and ozone injection rate was adjusted accordingly. Ozone injection rate was generally low on Monday and rainy day. Ozone injection rate distribution (Fig. 4) exhibited similar distribution pattern at the controlling dissolved ozone concentration between 0.1 and 0.3 mgO_3/L. At controlled dissolved ozone concentration of 0.3 mg O_3/L, 90% of the ozone injection rate was under 10mg O_3/L, and the average rate was 7.2 mgO_3/L.

Ceramic membrane cleaning by dissolved ozone is shown in Figure 5. Dissolved ozone concentration was measured just prior to the inlet of ceramic membrane element. Normally dissolved ozone concentration was controlled at or below 0.01 mgO_3/L. To clean the ceramic membrane elements by raw water with dissolved ozone, dissolved ozone concentration was set at > 0.1 mg O_3/L. TMP was observed to decrease from 50 to 35kPa (8 to 5 psi) in 5 hours. This result indicates that dissolved ozone can be an effective cleaning agent for membrane in particular for organics.

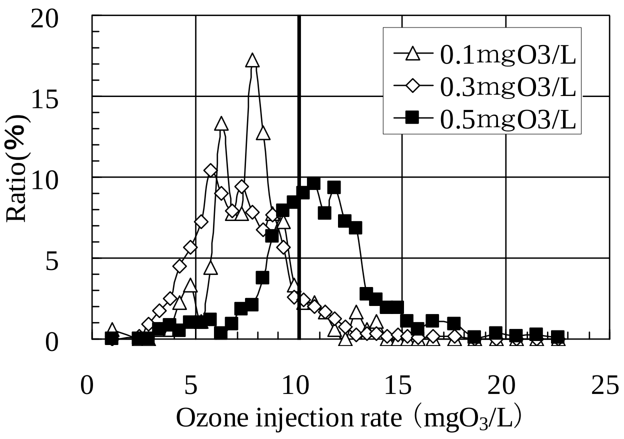


Figure 4. Ozone injection rate distribution

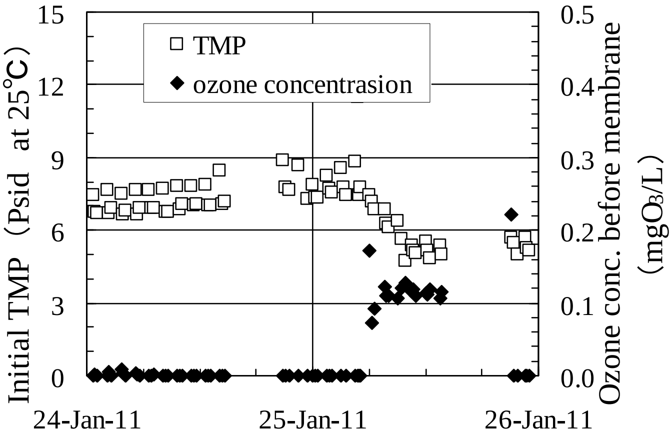


Figure 5. Ceramic membrane cleaning by DO_3

Quality of the filtrate

Water quality analysis for raw water and filtrate are shown in Table 5. The amount of Suspended Solids SS in raw water was 1.4 mg/L to less than the detection limit of 1 mg/L. Chemical Oxygen Demand with manganese (COD_{Mn}) and Dissolved Organic Carbon (DOC) were measured as markers for total organics. The COD_{Mn} removal ratio was 40 to 60%. The S-COD_{Mn} removal ratio was 50%. Filtrate turbidity was less than 0.1 NTU. Color was reduced to 1 Color Unit (1 color unit is measured with 1 m g Pt/L and 0.5 mg Co/L). Japan recreational water color standard in Japan is < 10 color units. As shown in Figure 6, membrane filtrate color and turbidity was stable.

Coliform level of 330-2800 Cell/100mL was detected in raw water, however, none was not detected in filtrate. Norovirus was also detected in raw water. Level, in the filtrate was less than 100, quantitative limit. Bacteria and virus was sufficiently removed.

Table 5. Raw water and filtrate quality

		Raw water	Biofilter Effluent	Ozone effluent	filtrate
SS	mg/L	1.4(0 – 5)	0.1(0 – 1)	–	<1
COD_{Mn}	mg/L	9.3(4 – 13)	7.4(3 – 11)	5.2(3 – 7)	3.8(1 – 5)
DOC	mg/L	5.9(3 – 8)	5.6(2 – 7)	5.6(2 – 7)	4.3(2 – 6)
T–P	mg/L	0.4(0.1 – 3.4)	0.3(0.1 – 1.6)	–	0.1(0.0 – 0.5)
Turbidity	NTU	1.6(0.3 – 7.7)	0.5(0.1 – 2.8)	0.2(0 – 0.7)	<0.1(0 – 0.6)
Color	Color Unit	15(4 – 23)	15(4 – 23)	2.8(0.9 – 4.4)	1.0(0.1 – 2.8)
Coliform	$100mL^{-1}$	330 – 2800	70 – 240	<1.8	<1.8
Norovirus	Copy/L	1400 870	2200 630	<100 <100	<100 <100

average (min - max), Norovirus : upper value=G1, lower value=G2

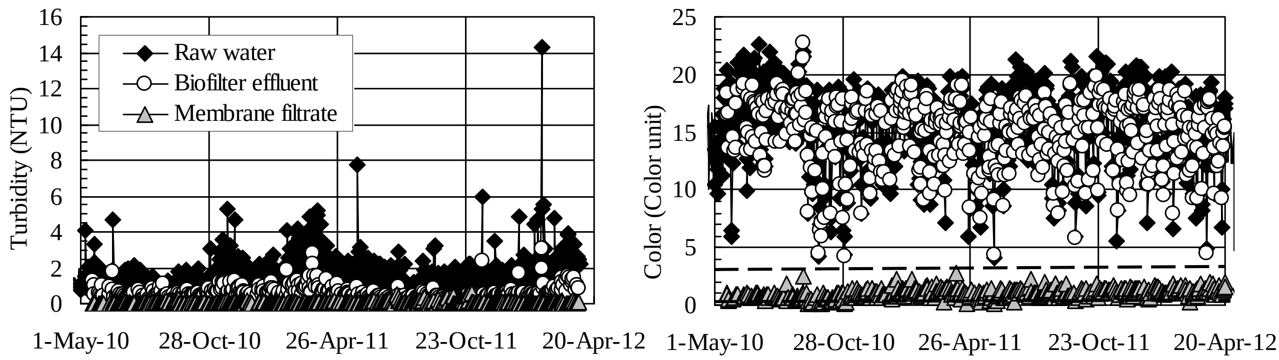


Figure 6. Stability of membrane filtrate quality

In reference to the Unrestricted Urban Reuse Standards in California which is known to be one of the most stringent for reclaimed water, filtrate from Shibaura reclaimed wastewater facility is in compliance. .

Conclusions

1) A hybrid system of pre-ozonation and coagulation followed by ceramic membrane filtration was found to be effective for reclaimed wastewater treatment.
2) Hybrid system can be operated with very high filtration flux of $4.2m^3/m^2/d$ (100gdf). Over 9 months stable membrane filtration has been demonstrated at the high flux without CIP.
3) Dissolved ozone is an effective means to remove organic foulants with no deleterious effect on ceramic membrane.
4) The hybrid system is effective for the removal of organic matters, COD_{Mn} by 50%, and color by about 80% as well as Bacteria and virus, and it produced safe water epidemiologically. The quality of the filtrate met the California standards.

References

B. Schichter, V. Mavrov and H. Chiel (2003), “Study of a hybrid process combining ozonation and membrane filtration – filtration of model solutions”, *Desalination*, 156:257-265.

H. Yonekawa (2002), “Development and Application of Ceramic Membrane Systems for Water Purification in Japan”, *Proceeding of Japan/Norway Workshop Membrane Filtration Technology for Water Treatment*, 30 September 2002, Tronheim, Norway, 15-19.

J. Bratby(2006), “Coagulation and Flocculation in Water and Wastewater Treatment”, IWA Publishing, 4(11):169-171.

K. Komatsu, A. Imai, H. Yonekawa, T. Hashimoto, N. Kawasaki, T. Satou and A. Kouzu(2011), “Characterization of dissolved organic matter in water reclamation process”, *The 4th IWA-ASPIRE Conference and exhibition*,11-5-3.

K. Takemura, M. Ohnishi, K. Noto, T. Murakami and H. Ohta (2003), “Research on MBR filtrate quality for reuse purpose”, *Proceeding of sewage system meeting for reading research paper*, 22-24 July 2003, Japan, 40: 685-687 (in Japanese).

M. Kiyozuka., M. Fujiwara, K. Yamamoto, H. Taniguchi, S. Kanaya, N. Murata and K. Hattori (2005), “Research for Application of Ceramic Membrane to Medium and Large-scale Water Purification Plant”, *AWWA Annual Membrane Tech. Conference*, 6-9 May 2005, Phoenix, AZ, USA.

M. Noguchi, S. Suzuki, T. Kato and Y. Kanto(2007), “The Study on the Ceramic Membrane Wastewater Reuse System with Pre Ozonation and Coagulation”, *6th IWA Specialist Conference on Wastewater Reclamation and Reuse for Sustainability Guiding the growth of water reuse*, 9-12 October 2007, Antwerp, Belgium, 60.

M. Noguchi, Aoki, H. Kozono, H. Kouchiwa and Y. Yoda (to be published), “The Study on the Ceramic Membrane Wastewater Reuse System with Pre Ozonation and Coagulation”, *Ozone Science & Engineering*.

N. Murata, H. Yonekawa, N. Aoki and K. Ito (2006), “Ceramic Membrane Filtration Treatment with applied Pre Ozonation before Coagulation”, *57th JWWA Annual Conference and Symposium*, 24-27 May 2006, Japan, 214-215 (in Japanese).
S. Lee, N. Jang and Y. Watanabe(2004), “Effect of residual ozone on membrane fouling reduction in ozone resisting microfiltration (MF) membrane system”, *Water Science and Technology*, 50(12):287-292.
S.Y.Moon, S.H. Ahn and S.W. Hong (2006), “Effect of the ozone-pretreatment in microfiltration membrane process for wastewater reuse”, *Proceedings of the Membrane Science &Technology* 27-28 April 2006, Singapore.
T.D.Wang, L. Wang, Y. Liu and W.S. Duan (2007), “Ozonation pre-treatment for ultrafiltration of the secondary effluent”, *Journal of membrane science*, 287:187-191.
U.S. Environmental Protection Agency. (2004) “Guidelines for Water Reuse”, Chapter4, Water Reuse regulations and Guidelines in the U.S. , 153-163.

Reclaimed wastewater facility using Ozone and Ceramic Membranes

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America's Authority in Membrane Treatment
AMTA
American Membrane Technology Association
Improving America's Waters Through Membrane Treatment and Desalting

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The Authoritative Resource on Safe Water®

METAWATER

Background

1. Water Reuse Project in Japan “Sewer Vision 2100”

   Water shortage in urban area, Tokyo, Yokohama, Kobe, etc.

   Encourage developing water reclamation technology

2. Increased reclaimed water demand

   Growing demand for water reuse of secondary effluent

   Non-portable reuse, Landscaping irrigation etc.

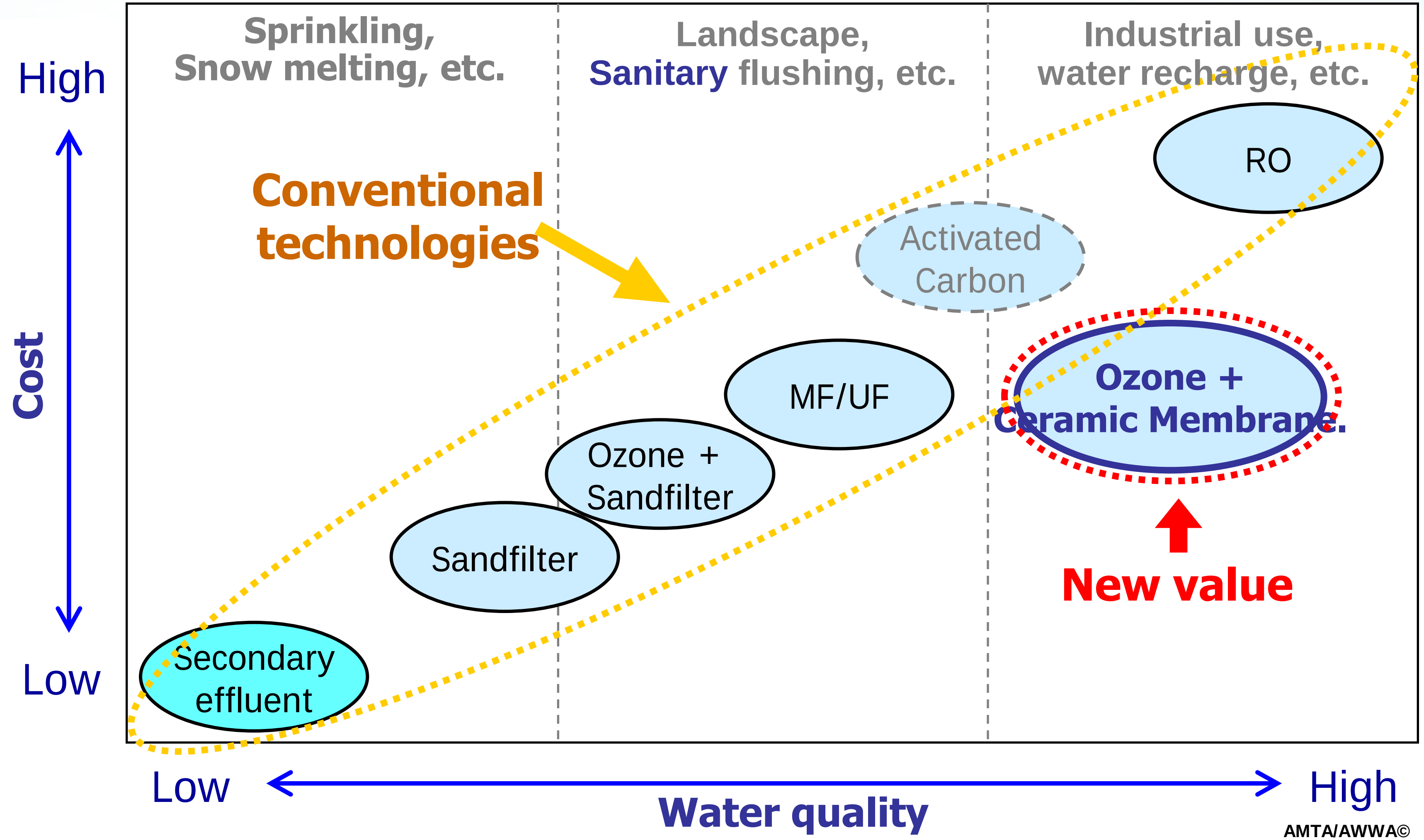
- METAWATER and Tokyo Metropolitan government have conducted collaborative research since 2006
- Full scale installation in 2010

Tokyo metropolitan government

- Population: 12 Million / Service area : 1,800km^2(700sq miles)
- Bureau of Water work
- 1,400MGD : Treated wastewater
- 130 MGD : reuse water for landscaping and sprinkling
- 100 MGD: use for non-portable reuse, sanitary flushing, etc
  - 1MGD ozone + polymeric membrane operated since 2005
  - 2MGD ozone+ ceramic membrane operated in 2010

Water reclamation development target

Produce "high quality" & "low cost" reclaimed water



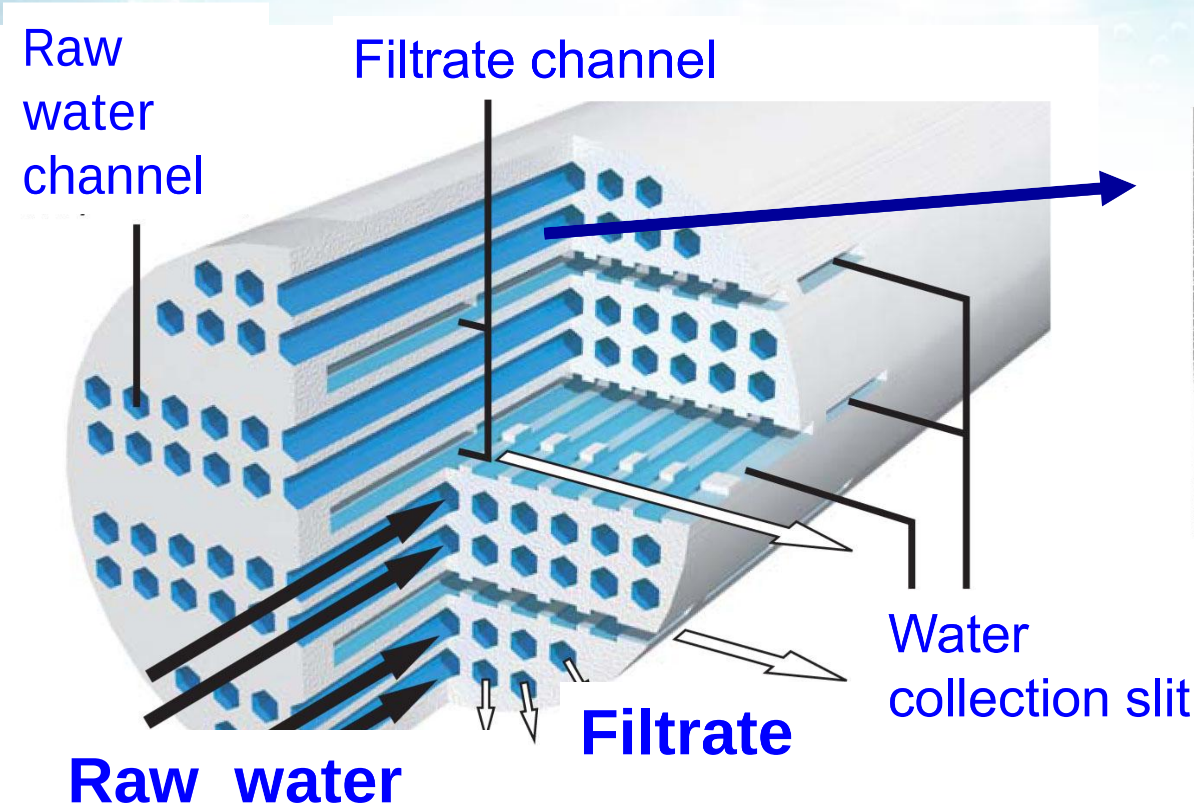
Benefit of Ceramic Membrane System

- **High quality water**
  - Mechanical strength
    - High integrity -No breakage
  - Uniform pore size distribution
    - Reliable physical separation
- **Water saving**
  - High feed water recovery >98%
- **Energy Saving**
  - Electric power consumption< 0.1 kWh/m^3 (0.38 Wh/gal)
- **Low Maintenance**
  - Long membrane Life >20years
  - Easy chemical cleaning
- **Design flexibility**
  - Combination with enhanced treatment (e.g.) coagulation, pre-ozonation, Powdered Activated Carbon (PAC)

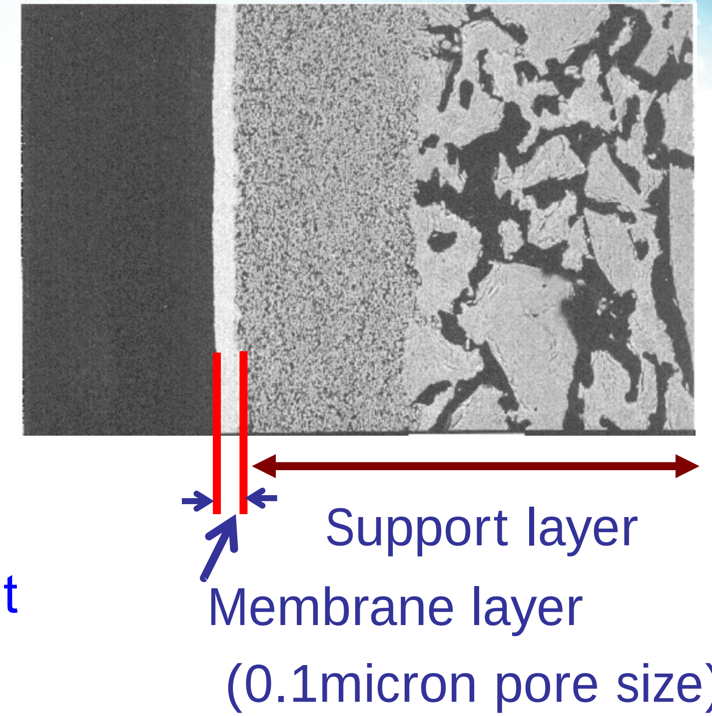
Ceramic Membrane Element

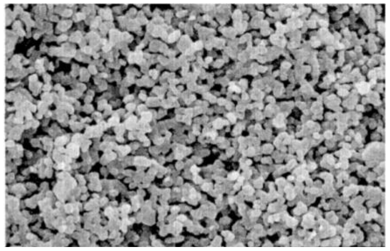
Nominal pore size	0.1micron
Dimension	180mm x 1,500mmL (7.1″ x 59.1″)
Membrane surface area	25m^2 (269ft^2)
Size of channel	2.5mm (0.1″)
Number of channel	2000
Material	Ceramic
Flow rate	18gpm at 100gfd

Ceramic membrane element



Cross section





Membrane Surface

Filtration and backwash process

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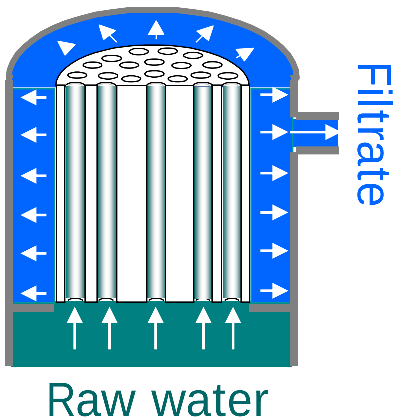
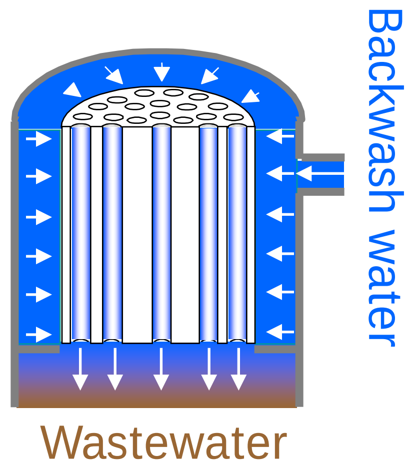
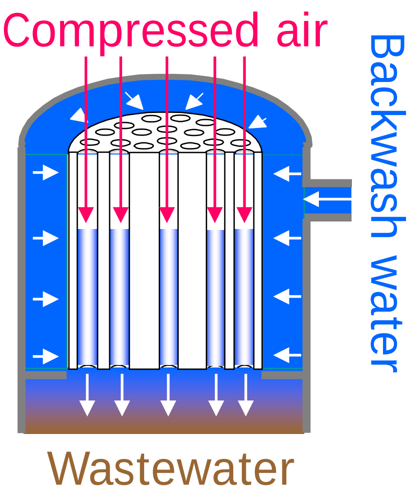
<tr><td>Schematic diagram</td><td>
</td><td>
</td><td>
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<tr><td>Operation Mode</td><td>Dead-end filtration</td><td>Reverse flow by filtrate</td><td>Air flushing by air/water</td></tr>
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Concept of combination of Ozonation/ Coagulation / Ceramic membrane

Ozonation

Microorganisms &
Virus Inactivation
Color and Odor Removal

Coagulation
Improvement

Coagulation

TOC & DOC Removal
Coagulate / pin floc reduces
TMP increasing rate

Fouling control

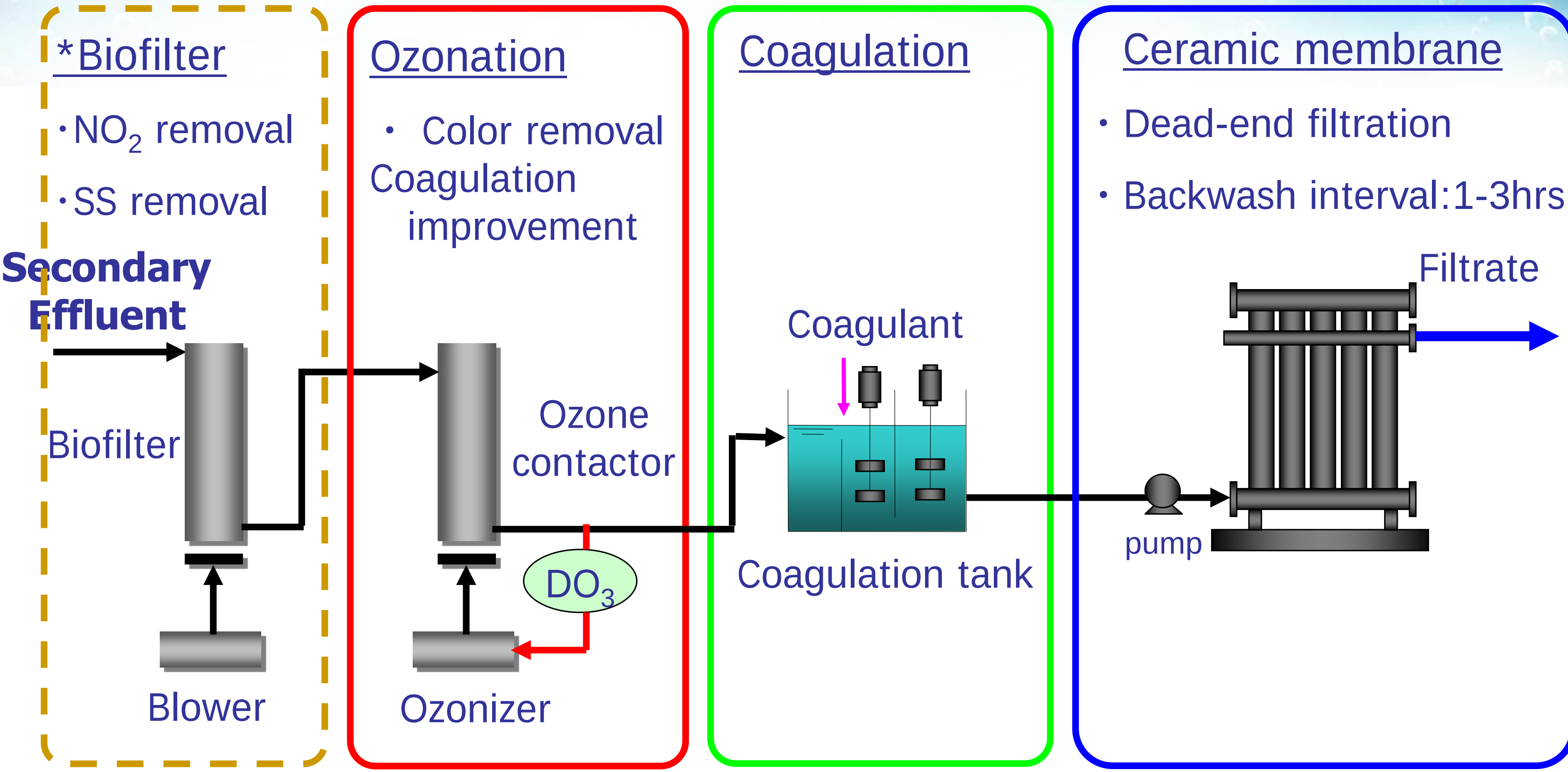
Ozone
Resistance

Ceramic Membrane

Turbidity / Particle Removal
High Flux
Stable Operation
Robustness

>120 installation, No breakage to date
since first installation in1998

Schematic flow of Water reclamation system



*** Biofilter process is optional**

Operation Result

- Test site: Shibaura WWTP, Tokyo
- Raw water: Secondary effluent
- Flow: Biofilter-O_3-coagulation- MF ceramic membrane

- Pilot testing
  - Period: 2006-2008
  - Single membrane module unit

- Full scale operation
  - 1.8 MGD (108 membranes)
  - Start up April 2010

Pilot test - Equipment

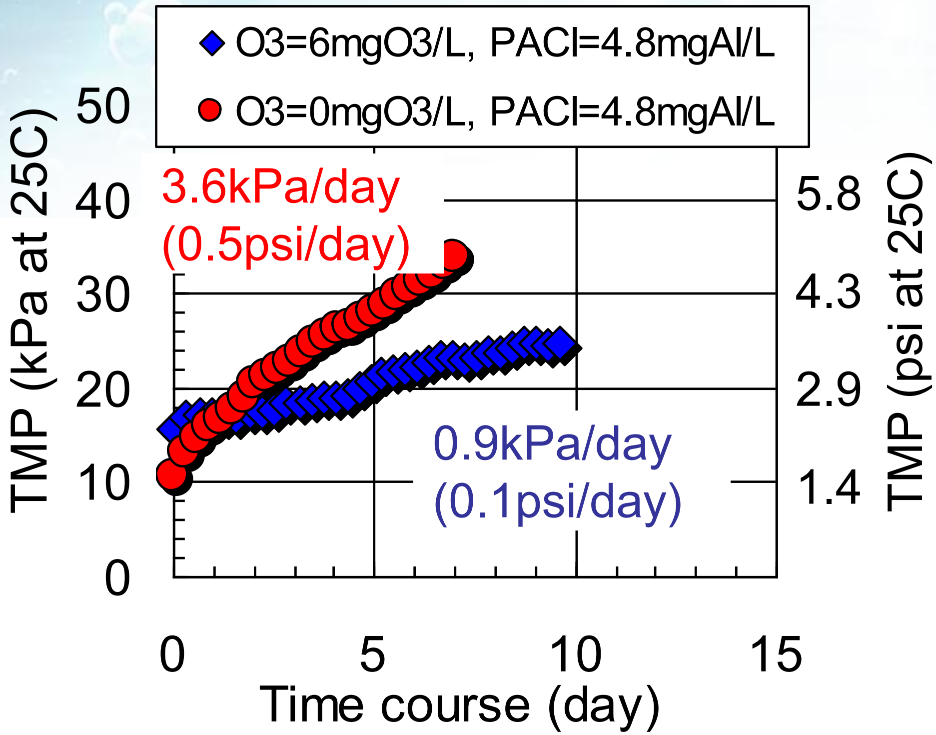
Ozone Contactor

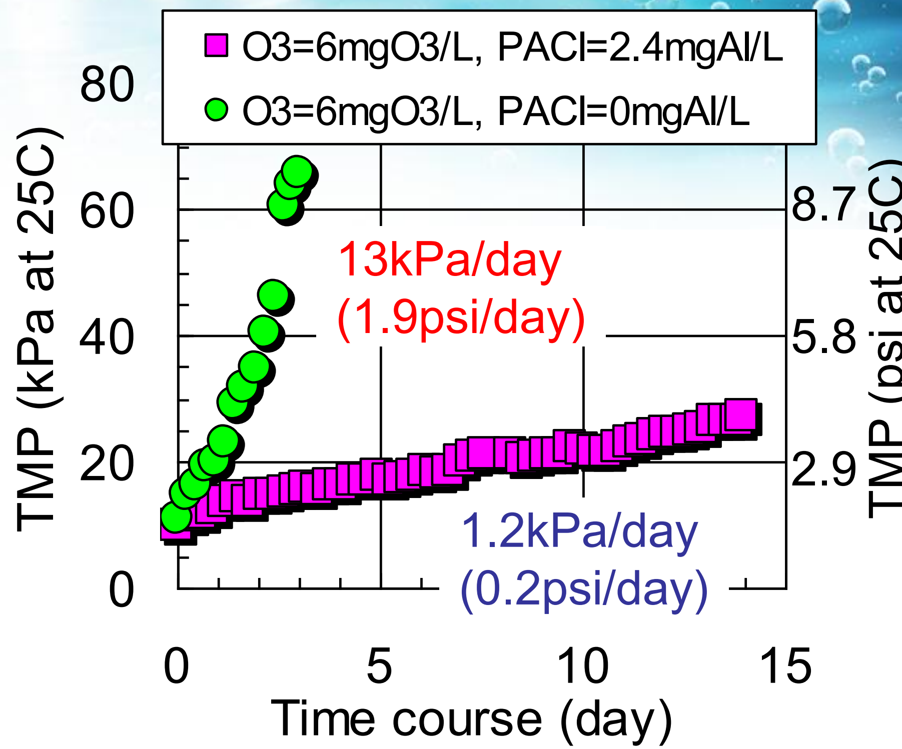
Ceramic Membrane unit

Single membrane unit

Capacity: 18.3gpm at 100gfd

Pilot test - Results (ozonation / coagulation effect)





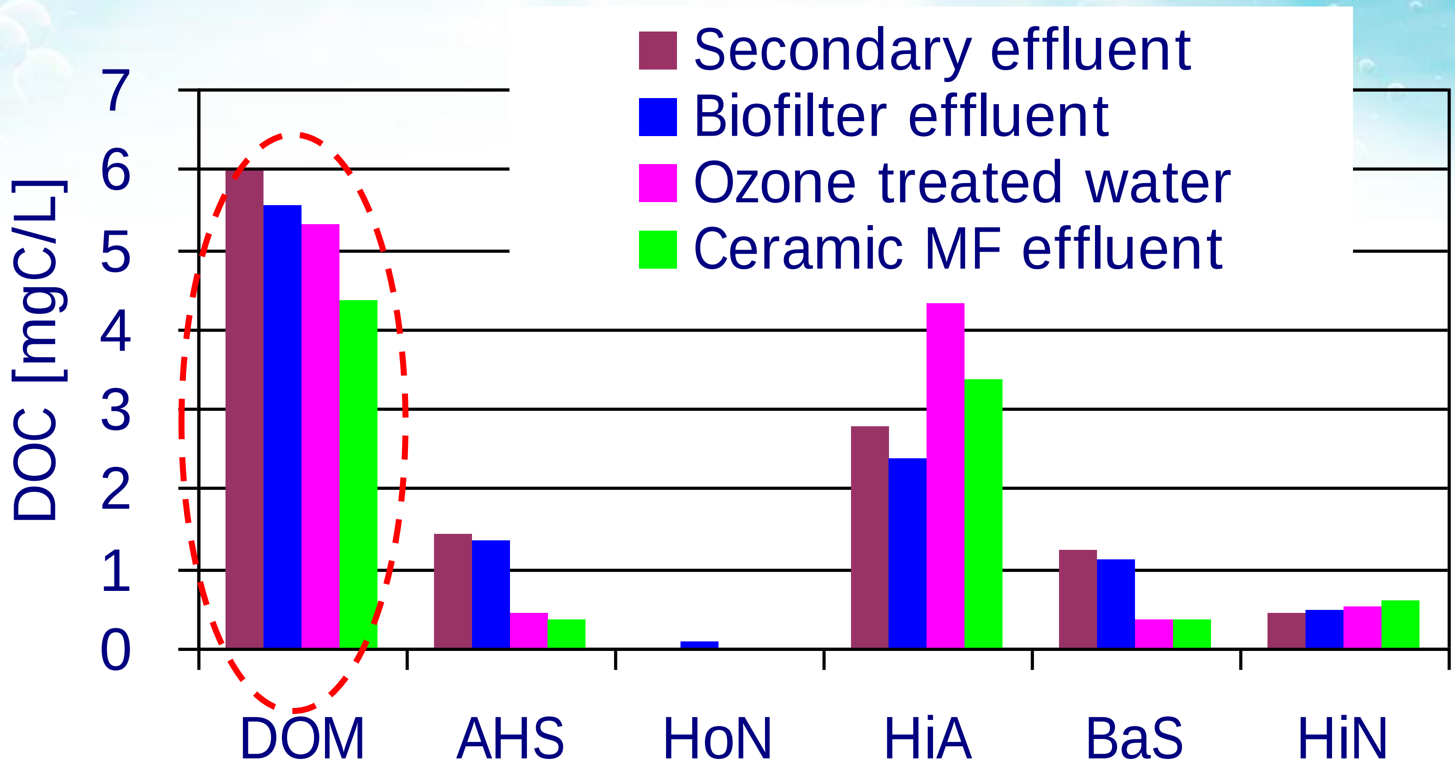
Preozonation effect on TMP increase

TMP increase rate reduced 1/4 by ozonation

PACl coagulation effect on TMP increase rate

TMP increase rate reduced 1/10 by coagulant(PACl)

Pilot test - TOC fraction distribution

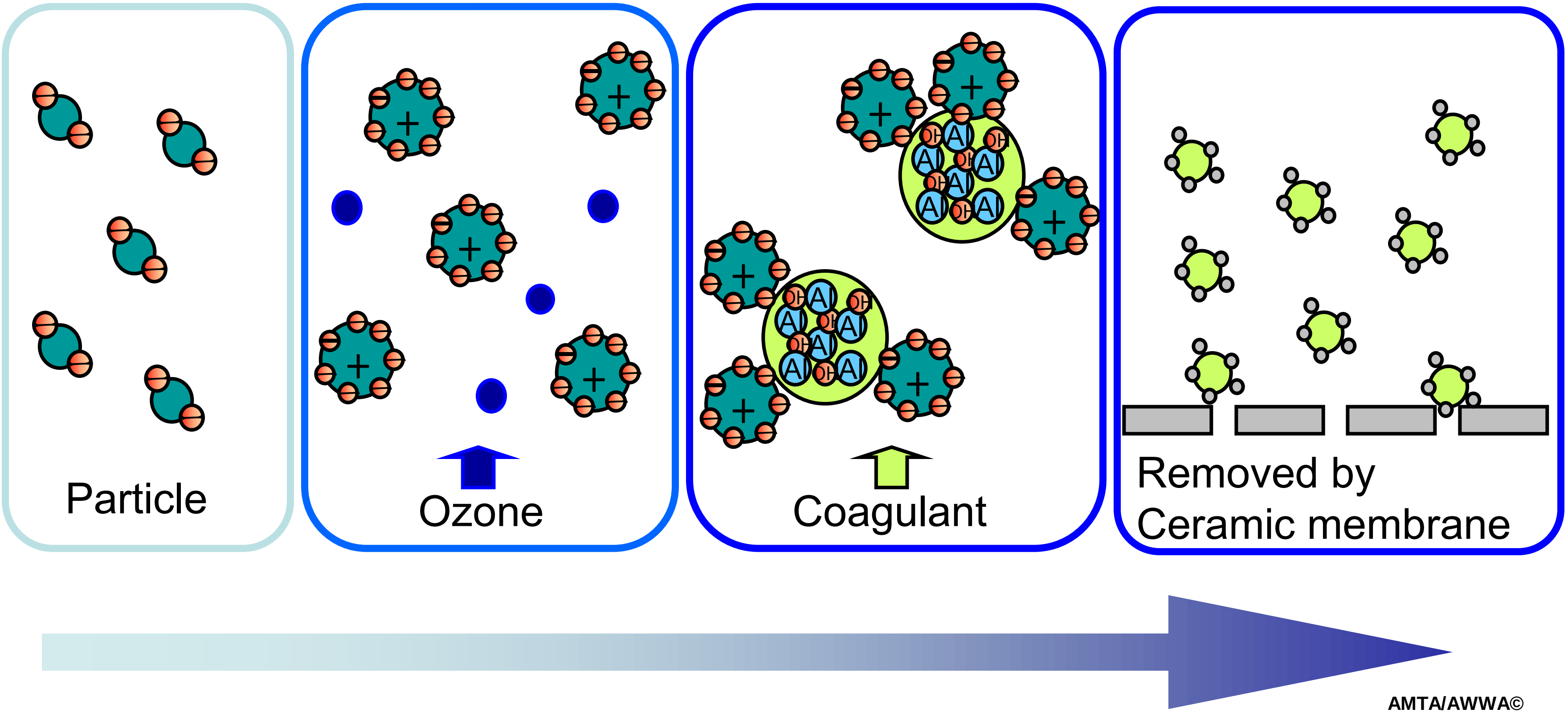


DOM: Dissolved Organic Matter

- **AHS:** **Hydrophobic Acid**
- **HoN:** **Hydrophobic Neutrals**
- **HiA:** **Hydrophilic Acid**
- **Bas:** **Bases**
- **HiN:** **Hydrophilic Neutrals**

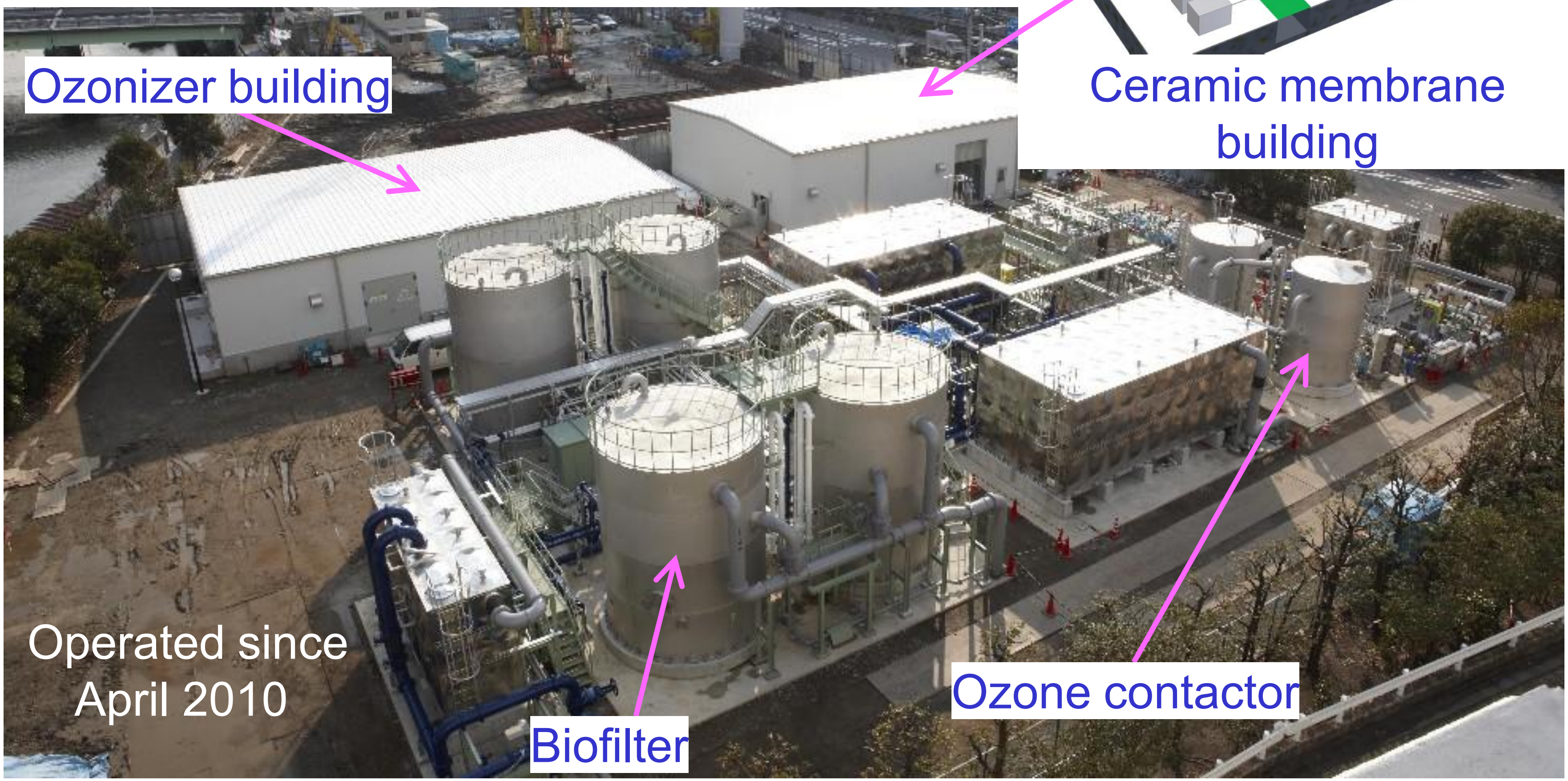
Pilot test - Coagulation enhancement by ozonation

1. Ozone imparts negative charge to particles
2. Negative charged particles attract to positive charged coagulant
3. Neutral floc formed course high permeability cake layer



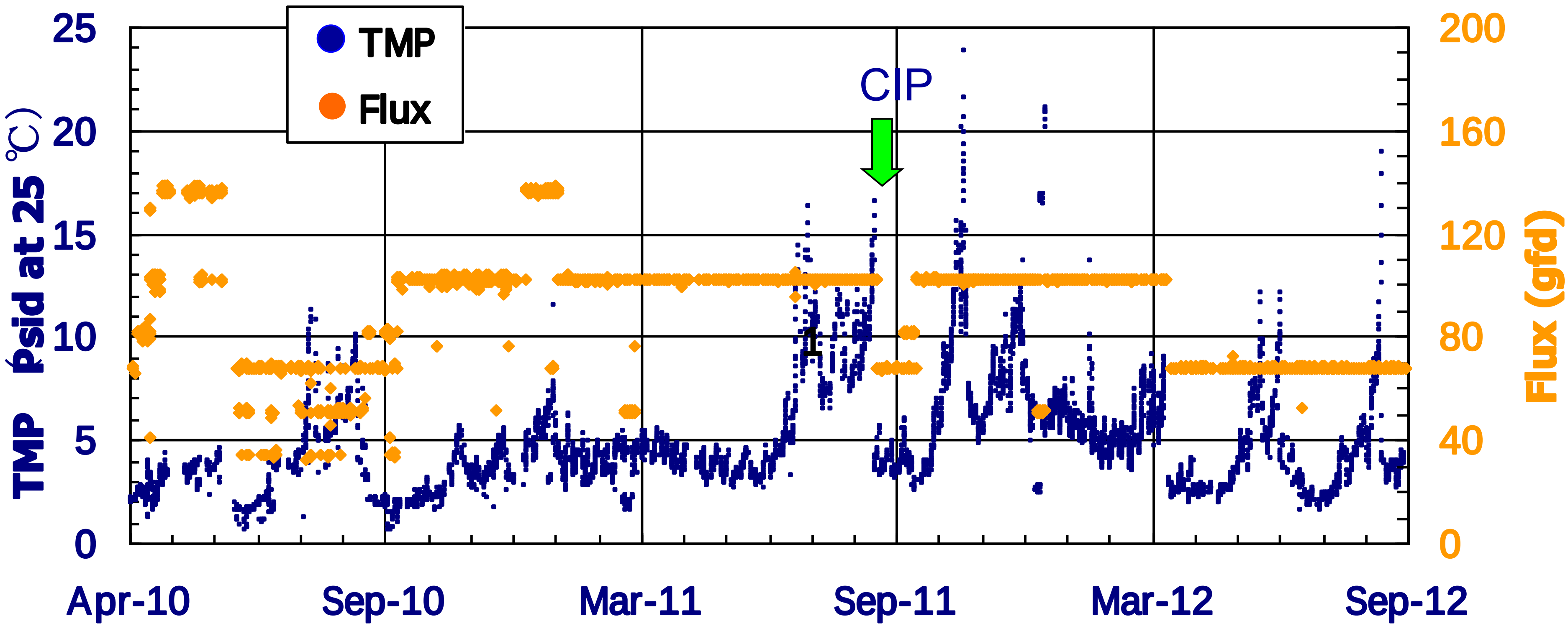
Full scale installation (Shibaura WWTP)

- **Capacity : 1.85MGD (7,000 m³/day)**
- **Biofilter : φ4.5m x 4 tanks = 120 m/day**
- **Ozonizer : 133ppd 2.5 kg-O_3/hr x 2**
- **Ceramic membrane : 54membrane x 2units**



Full scale operation – TMP Long term

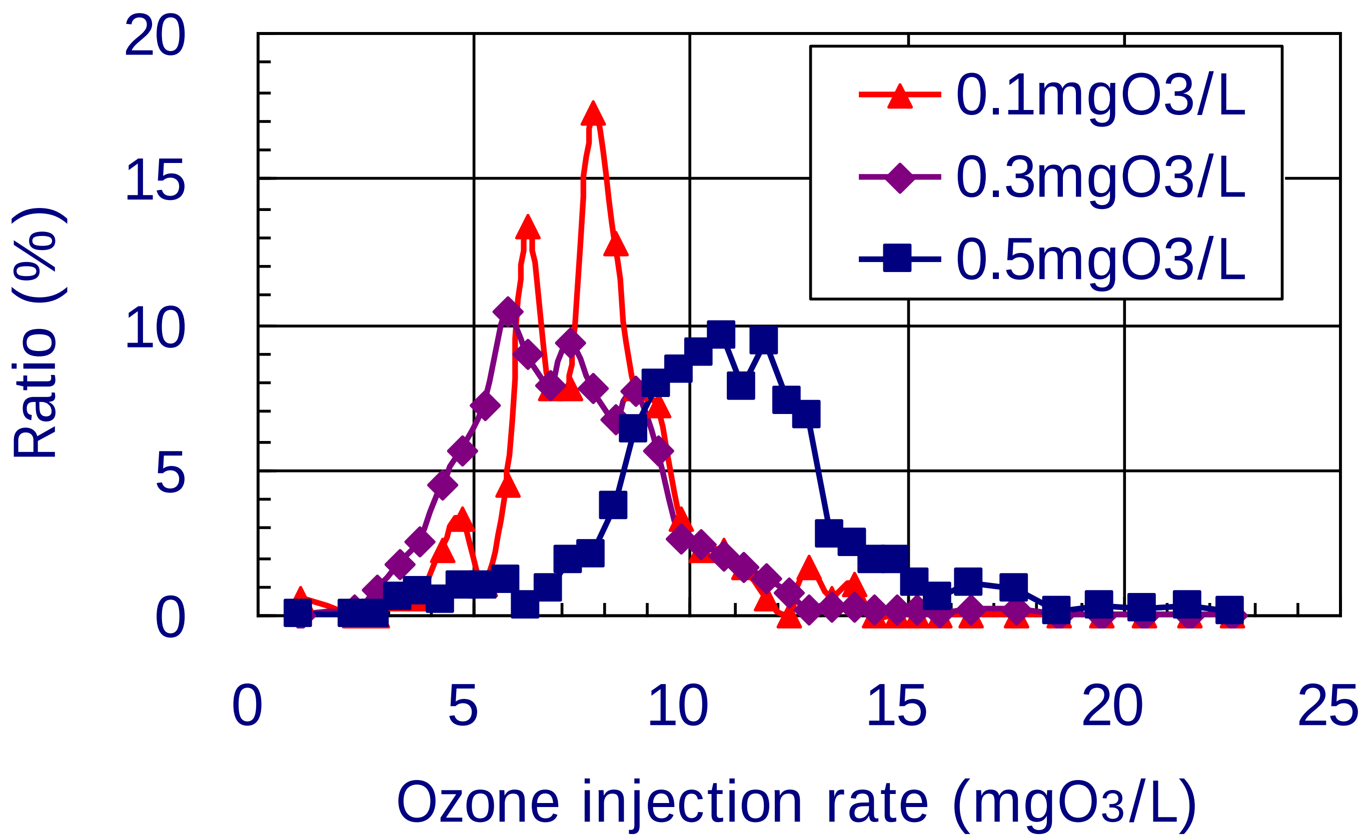
★Residual O3 : 0.1 ~ 0.5mgO3/L (0.3 mg/L more than 90% of time)
★pH control : 6.3 ~ 6.8
★PACl dosage : 20 ~ 68mgPACl/L



Over 9 months - stable membrane filtration demonstrated at the high flux without CIP.

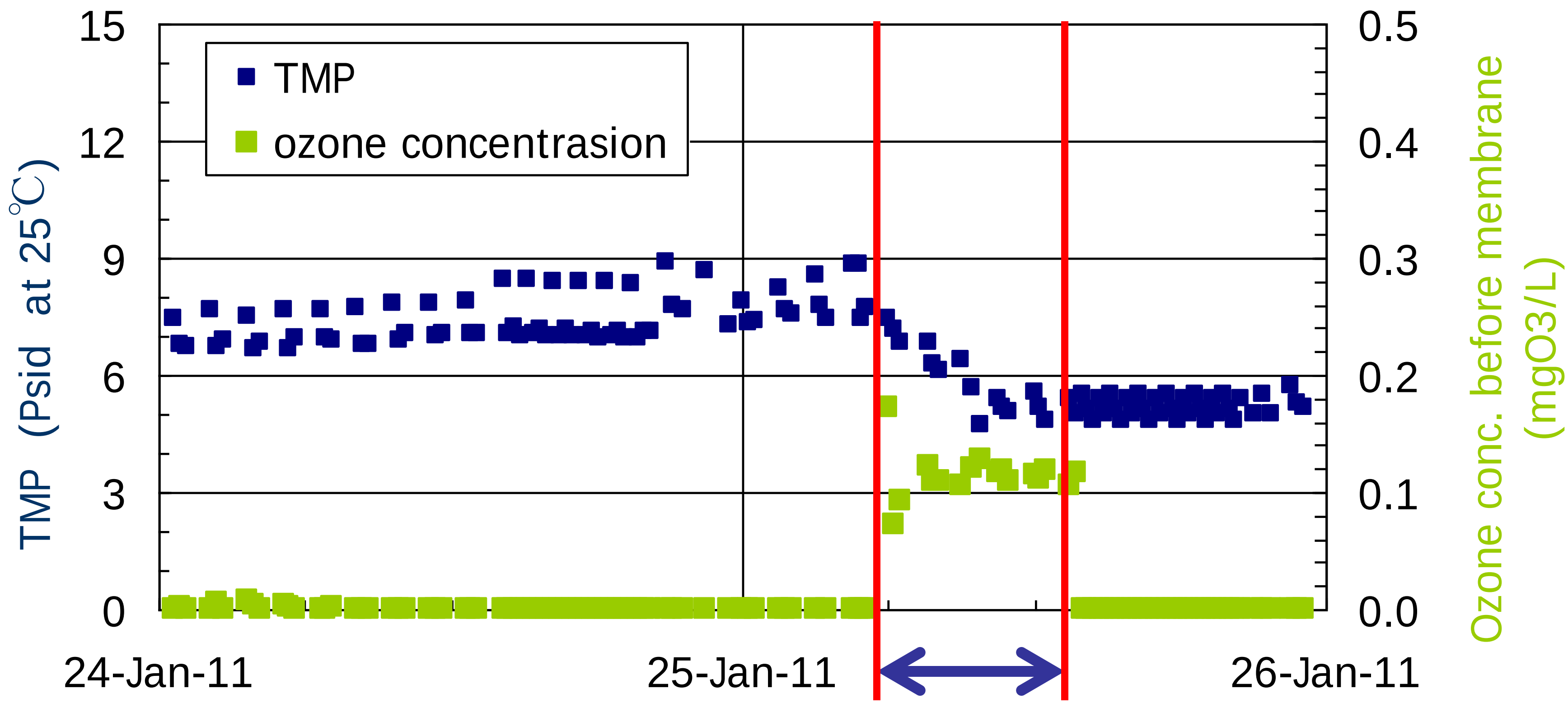
Full scale operation - Distribution of ozone injection rate

Dissolved ozone concentration of ozone contactor effluent



- Dissolved ozone of 0.3mg/L
- Average ozone dosage : 7mgO3/L

Full scale operation –
Membrane Cleaning by residual ozone



Ozone cleaning period
Ozone residual 0.1mg/L

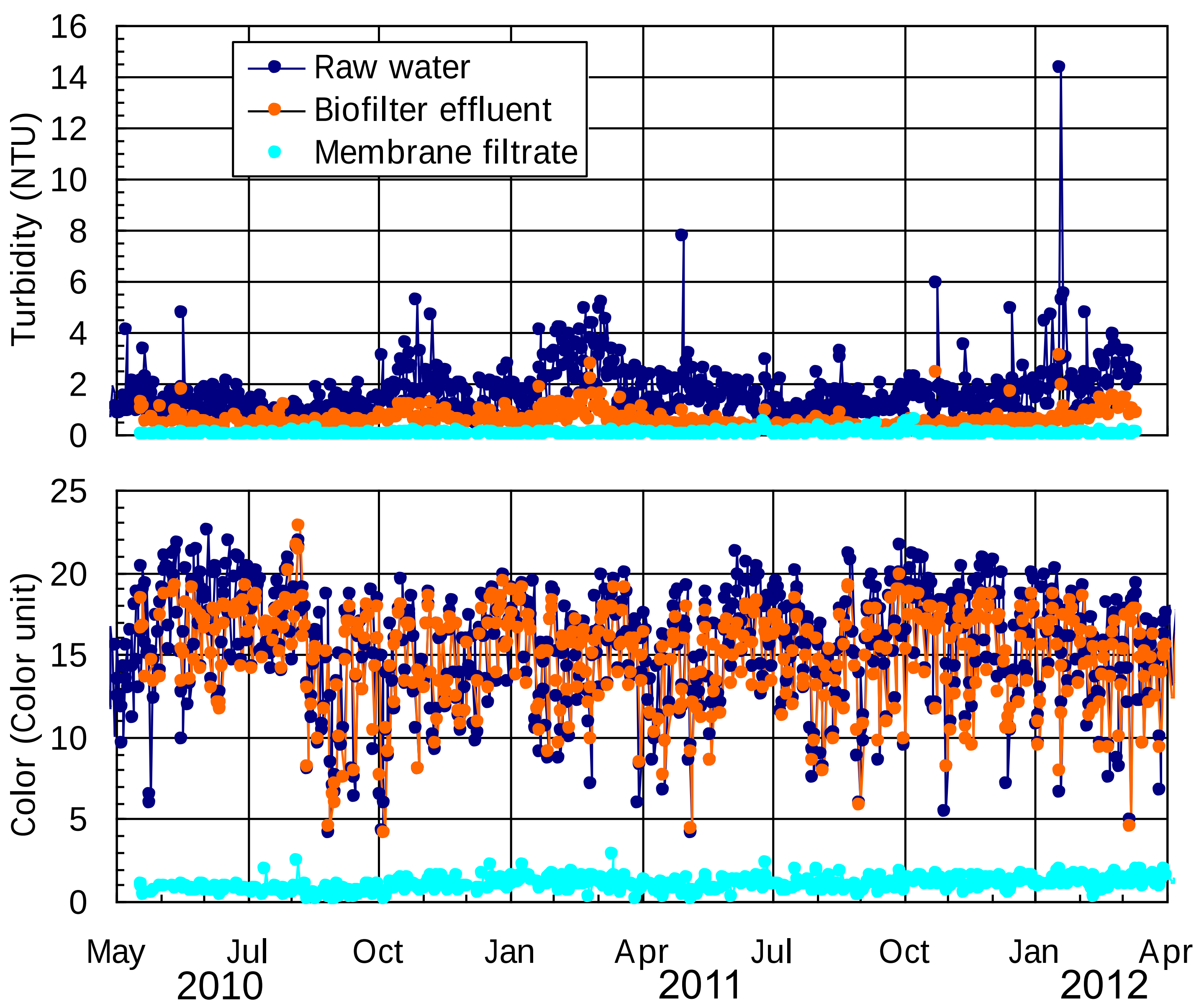
Full scale operation - Reclaimed water quality

		Raw water (2nd effluent)	Biofilter effluent	Ozone effluent	Ceramic membrane filtrate	Target Value
SS	mg/L	1.4 (0 – 5)	0.1 (0 – 1)	–	<1	n/a
COD	mg/L	9.3 (4 – 13)	7.4 (3 – 11)	5.2 (3 – 7)	3.8 (1 – 5)	n/a
DOC	mg/L	5.9 (3 – 8)	5.6 (2 – 7)	5.6 (2 – 7)	4.3 (2 – 6)	n/a
T－P	mg/L	0.4 (0.1 – 3.4)	0.3 (0.1 – 1.6)	–	0.1 (0.0 – 0.5)	n/a
Turbidity	NTU	1.6 (0.3 – 7.7)	0.5 (0.1 – 2.8)	0.2 (0 – 0.7)	<0.1 (0 – 0.6)	<1
Color	Color Unit	15 (4 – 23)	15 (4 – 23)	2.8 (0.9 – 4.4)	1.0 (0.1 – 2.8)	3
Coliform	MPN /100mL	330 – 2800	70 – 240	ND	ND	Not detected
Norovirus	Copy/L	1400 870	2200 630	ND	ND	n/a

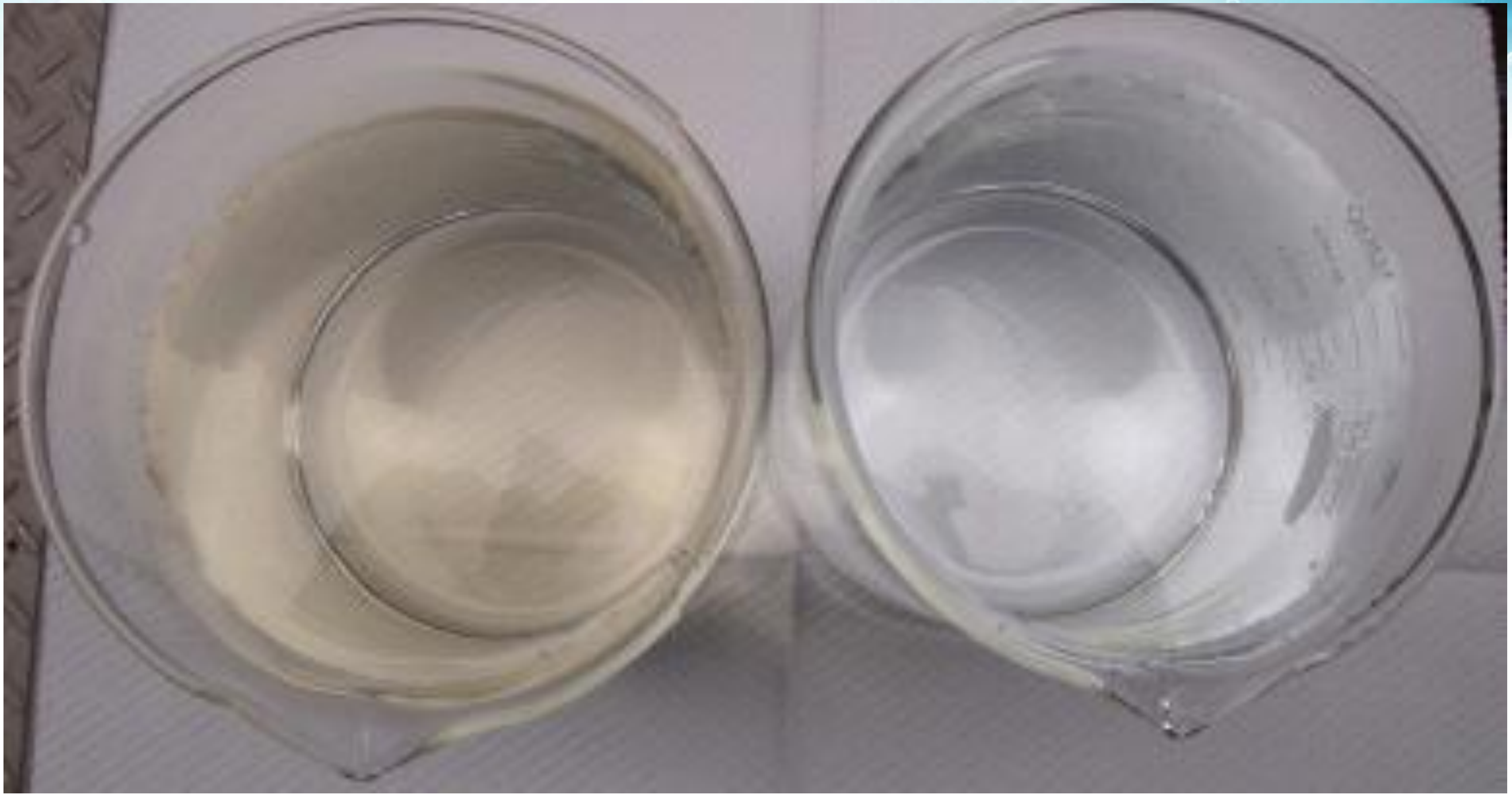
average (min. – max.)

Norovirus : upper value=G1, lower value=G2

Full scale operation - Turbidity & color



Full scale operation - Water quality
Color removal



Raw water (Secondary effluent) Membrane filtrate

Conclusions

1) A hybrid system of pre-ozonation /coagulation/ceramic membrane filtration was highly effective for reclaimed wastewater treatment.

2) Hybrid system operated with very high filtration flux of $4.2 m^3/m^2/d$ (100gfd) for over 9 months; stable membrane filtration demonstrated without CIP.

3) Dissolved ozone was effective to remove organic foulants with "NO" deleterious effect on ceramic membrane.

4) Hybrid system was effective for the removal of organic matters, COD_{Mn} by 50%, and color by about 80% as well as Bacteria and virus, and produced safe water epidemiologically. Quality of the filtrate met the California standards.

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METAWATER