

## **Introduction to Submerged Flat Sheet Membrane Applications and Its Future Direction to be Headed**

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### **Abstract**

It has been thirteen years since the first wastewater treatment plant with KUBOTA submerged flat sheet membrane bioreactor (MBR) was installed in Japan. Since then KUBOTA submerged flat sheet MBR has been pioneered mainly in three different applications; municipal/domestic wastewater treatment, water reclamation, and industrial wastewater treatment. So far, more than 1100 installations have been built in Japan, and a total of more than 1200 installations has been built around the world (as of October, 2003).

The recent prospected trend in submerged membrane installations is that in order to preserve water quality and conserve water resource on the earth, the increased need of MBR as new wastewater reclamation technology is expected around the world. This paper explains KUBOTA submerged flat sheet membrane installation patterns in both Japan and oversea markets. Then, it presents a basic explanation on KUBOTA submerged flat sheet membrane bioreactor system and its actual applications in both Japan and overseas. Moreover, further studies done on membrane bioreactor technology for reuse are presented. Thus, further direction a submerged membrane application to be headed should be clearly pronounced.

### **Introduction**

In Japan, there are by far more membrane installations in wastewater treatment application than water treatment application as shown in the Table 1. The data in the table on membrane installations applied in wastewater treatment are only the installations of KUBOTA Submerged Membranes in Japan. On the other hand, installations in water treatment application show all the installations in both public and private sectors in Japan. The advantages of submerged membrane bioreactor which includes superior organic removal, enhanced nutrient removal stability, lower sludge

production, smaller footprint, well microbial rejection and high loading rate capabilities, have led the increased attention by various wastewater treatment field.

Table 1. Comparison of Membrane Installations in Japan

Year	KUBOTA Membrane Technology Applied in Wastewater Treatment Plant (Both Public & Private Sectors)	Membrane Technology Applied in Water Treatment Plant (Both Public & Private Sectors)
1993	1	7
1994	5	2
1995	18	10
1996	35	25
1997	70	24
1998	130	40
1999	129	55
2000	208	40
2001	208	50
2002	231	38
2003	114	30
Total	1149	321

Ever since the first wastewater treatment plant with KUBOTA submerged membrane bioreactor was installed in Japan in 1990, there has been an abrupt increase in number of installations in the following decade. KUBOTA submerged membrane unit is utilized in a various plants, such as municipal wastewater treatment, domestic/rural community wastewater treatment, Johkaso (residential septic tank which submerged membrane units are embedded), industrial wastewater treatment and water reclamation. Nowadays, in order to prevent eutrophication in a closing nature water area, such as inland sea and inside a bay, a more stringent discharge regulation (5<sup>th</sup> Total Water Quality Regulation) is to be implemented in Japan. Consequently, more and more needs in MBR technology are expected in Japan. Not only in Japan, but also overseas, such as the United States (US), Australia, Singapore and others, have seen an increased need in a use of reclaimed wastewater because of water scarcity. Thus, a continuous change in MBR installation trend should be expected.

### **KUBOTA Submerged Flat Sheet Membrane Installation Trend**

Detailed KUBOTA submerged flat sheet membrane installation records in both Japan and overseas from the year of 1997 to 2003 are summarized in the following table (Table 2.) As it is clearly shown in the table, membrane installations have kept increasing from year to year.

Table 2. Installations and Sales Distribution by Total Membrane Area

Year	Municipal WWTP	Private Johkaso	Water Reclamation/Grey Water Recycle	Industrial	Overseas	Total
1997	1,120	7,680	0	4,120	2,880	15,800
1998	3,040	20,980	2,440	4,940	9,360	40,760
1999	6,340	20,880	2,980	8,468	17,280	55,948
2000	3,840	33,880	680	11,760	26,860	77,020
2001	10,680	29,140	2,640	32,560	28,000	103,020
2002	7,340	29,740	4,920	27,280	21,880	91,160
2003	6,360	12,381	1,360	15,080	71,740 (Approx. 168,000 Sales Expected)	106,921
Total	38,720	154,681	15,020	104,208	178,000	490,629

The next table, Table 3, compares membrane application distributions in 1997 to 2003. As it is summarized in Table 3, if the total membrane area installed in 1997 to be set to 1, it is observed approximately seven times more installations in 6 years. If the installation distributions are examined carefully, the installations in private Johkaso plant, which dominated nearly a half of total membrane area installed in 1997, are decreased to account only 12% of the total in 2003. While an increase in overseas demands to 67% from 18% is observed in 6 years.

Table 3. Comparison on Membrane Installation Distribution in 1997 to 2003

Year	1997	2003
Total Membrane Area (Set a total membrane area installed in 1997 to be 1.0)	1.0	6.8
Installation Distribution by Total Membrane Area		
1. Municipal WWTP/Rural Community WWTP	7.1%	6.0%
2. Private Johkaso Plant	48.6%	11.7%
3. Water Reclamation/Grey Water Recycling System	0%	1.3%
4. Industrial	26.1%	14.2%
5. Oversea	18.2%	66.8%
Total	100%	100%

Furthermore, Table 4 distinguishes between Japanese and overseas installation distributions. It is noticeable that municipal application is by far accepted overseas than it is in Japan from the beginning. It shows that Japanese authority tends to take more time to allow adopting new technology than overseas. Moreover in Japan, a moderate increase in industrial wastewater treatment utilization is observed. It is because of the stringent discharge regulation (5<sup>th</sup> Total Water Quality Regulation) to be implemented in Japan from 2004. In Tokyo, there is also an obligation to install a grey water recycling system in an office building with a total floor area of 30,000m<sup>2</sup> or more. Thus a slight increase in water reclamation/grey water recycling system demand

is seen. While Japanese installations only tripled in 6 years, overseas demands are increased by 25 times from 1997 to 2003. From the data on overseas installations in 2003, it is considered that applications in industrial and water reclamation system are gradually increasing.

Table 4. Comparison on Membrane Installation Distribution in Japan to Overseas

Subjected Market Year	Japan		Overseas	
	1997	2003	1997	2003
Total Membrane Area (Set a total membrane area installed in 1997 to be 1.0)	1.0	2.7	1.0	24.9
Installation Distribution by Total Membrane Area				
1. Municipal WWTP/Rural Community WWTP	8.6%	18.1%	100%	89.6%
2. Private Johkaso Plant	59.4%	35.2%	N/A	N/A
3. Water Reclamation/Grey Water Recycle System	0%	3.9%	0%	0.4%
4. Industrial	31.9%	42.9%	0%	10.0%
Total	100%	100%	100%	100%

### Flat Sheet Membrane and Typical Submerged Membrane Reactor System Flow

KUBOTA Submerged Membrane Unit is composed of membrane case and diffuser case as shown in Fig. 1. In the membrane case, a flat membrane sheet sits at 0.7mm intervals, as also shown in Figure 1. A flat membrane plate, Membrane Cartridge, is constructed by ultrasonically welding sheets of chlorinated polyethylene on both front and back of ABS resin membrane panel. Membrane sheets have nominal pore size of 0.4-micrometer. Between the panel and the membrane sheets, a spacer is laid to distribute filtered water into a series of channels that lead to a nozzle on top of the cartridge. Moreover the spacer prevents membrane sheets from sticking onto the membrane panel.

Treated water is filtered out and collected through the nozzle by two methods; Gravity and Suction. By Gravity filtration method, a water head from upper side of unit to liquid surface, as a filtration driving force, naturally permeates out biologically treated water. Meanwhile, by Suction filtration method, permeate is forcibly discharged by a negative pressure on permeate side of the unit that is made by suction pump.

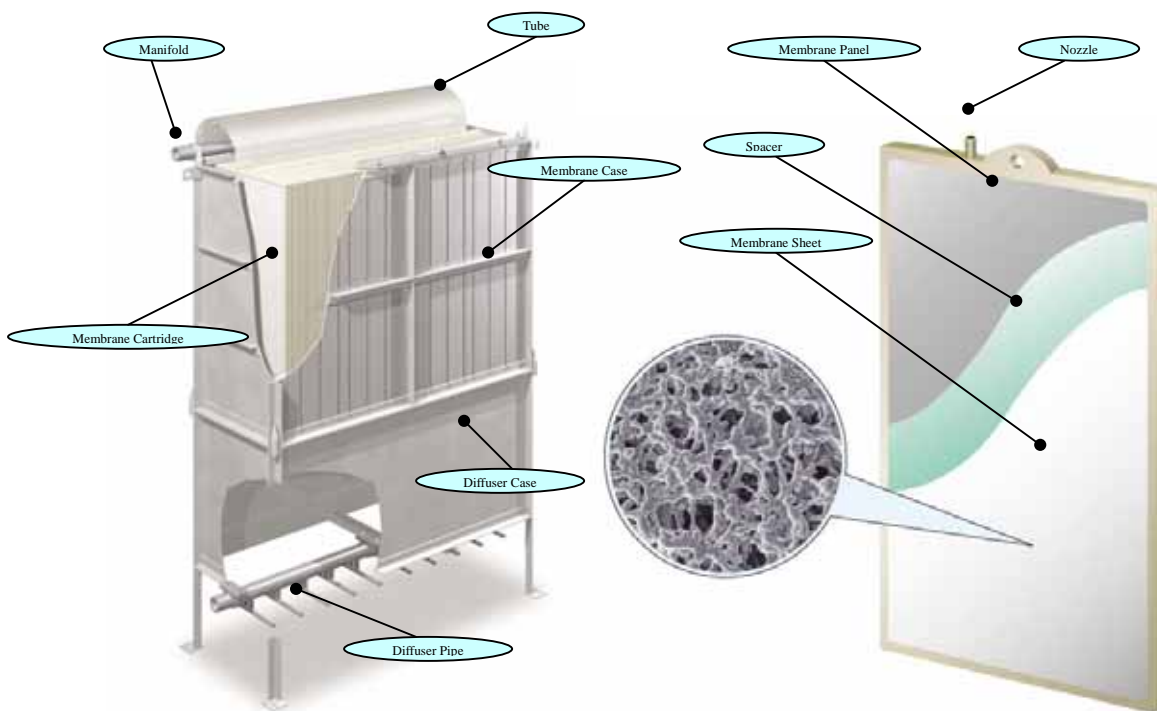


Figure 1. KUBOTA Submerged Membrane Unit and Flat Plate Membrane Cartridge

On the other hand, diffuser case, composed of casing and diffuser, supports membrane case as well as supplies air. The supplied air has three roles; to provide adequate oxygen for biological treatment, to scour the membrane surface to prevent fouling, and to create a specific density gradient between the inside and outside of the Submerged Membrane Unit, which produces MLSS circulation shown in Figure 2.

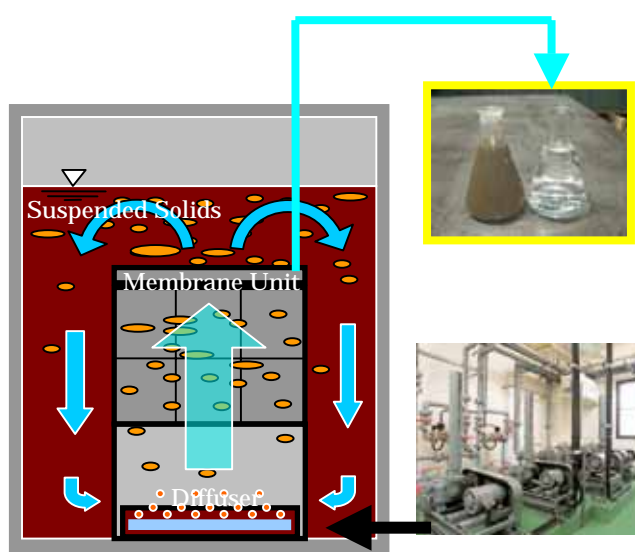


Figure 2. Bubble Distribution and MLSS Circulation

Membrane Bioreactor (MBR) is developed from conventional activated sludge system by simply installing Membrane Units in the aerated tank stage, as shown in Figure 3.

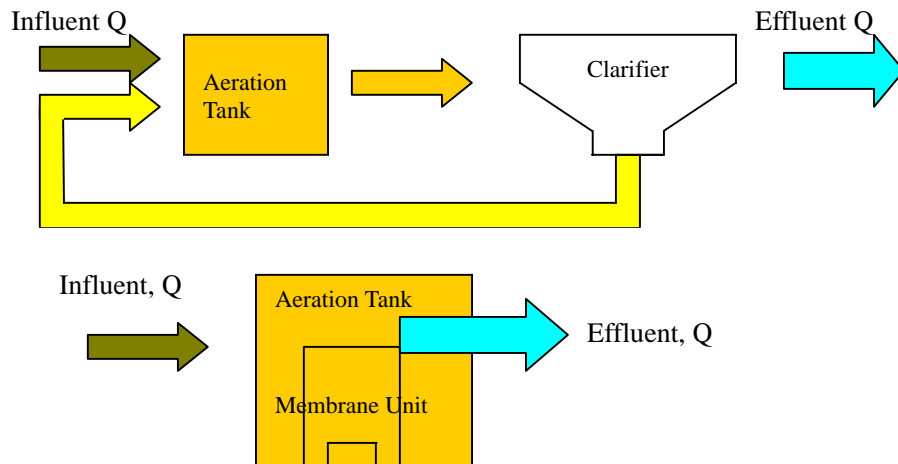


Figure 3. Flow Diagram Comparison of Conventional Activated Sludge System to Membrane Bioreactor System

Submerged flat plate membranes in MBR serve as a physical barrier; preventing passage of contaminants while allowing the free passage of biologically treated water. Thus, utilizing submerged membranes eliminates the need for secondary clarification and tertiary filtration. By decoupling the activated sludge process from the settling characteristics of MLSS, the footprint of a wastewater treatment process can be more or less halved.

## Actual Applications in Japan

Here introduces one of excellent installations in industrial wastewater treatment application in Japan. This case study shows the submerged membrane bioreactor installation at a laundry factory. Laundry industry is one of the industries that utilizes a great amount of fresh water and produces wastewater with high contaminants. In order for the factory to desalinate and reuse effluent, factory also installed reverse osmosis (RO) system following the submerged membrane bioreactor. Figure 4 shows a process flow diagram, and Table 5 summarizes the design criteria.

Table 5. MBR Design Criteria at Laundry Factory in Japan

Parameters	Raw Wastewater	MBR Permeate
Design Flow	290 m <sup>3</sup> /day	
pH	7.4	7.7
BOD	275 mg/L	2.7 mg/L
COD <sub>Mn</sub>	545 mg/L	13 mg/L
T-N	11.7 mg/L	5.0 mg/L
T-P	7.4 mg/L	4.2 mg/L
Numbers of Membrane Cartridges	900 pieces	
Volume of Membrane Bioreactor	97 m <sup>3</sup>	
Average Flux	0.4 m <sup>3</sup> /(m <sup>2</sup> *day)	

Submerged membrane bioreactor system was utilized to simplify treatment in the way of preliminary treatment to RO system. When utilizing such a water reuse system, the factory can conserve 70 to 80 % of water supply budget.

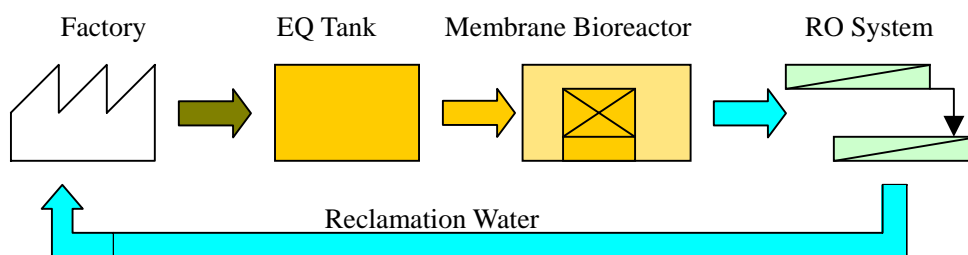


Figure 4 Process Flow Diagram for Membrane Application

## Overseas Installation Example

Countries, such as the US and Australia, that suffer from chronic water shortage have seen an increased use of advanced wastewater treatment technology in order to recycle and conserve water resources. In such countries, advanced treated water is used for golf course irrigation or simple land irrigation.

There is Submerged Membrane installation at a golf facility on the coast of Southern Oregon (Fig. 5). MBR technology was selected in order to expand the facility wastewater flow from 85m<sup>3</sup>/day to 945m<sup>3</sup>/day and to meet strict nitrate limits. The footprint of the plant is approximately 4m by 17m, which includes denitrification, pre-aeration, and nitrification (MBR) tanks. The effluent typically contains non-detectable amounts of SS, less than 8 mg/L T-N and less than 5mg/L BOD. Finally, disinfected effluent is utilized for the golf course irrigation.



Fig. 5 Oversea MBR Installation for Land Irrigation

### **Fouling Index or Silt Density Index (FI/SDI) Study for MBR Permeate Reuse**

In order to reuse MBR permeate, it is rather recommended to treat the permeate with Reverse Osmosis (RO) membrane unless only less than 50% of treated water is required to be reused, as in case of typical land irrigation. Since RO tends to foul more easily, Fouling Index or Silt Density Index (FI/SDI) test is used to determine the fouling potential of water feeding a membrane filtration process such as RO system.

In general, it is said that suitable FI/SDI value for RO module is from 4 to 5 or less, and that of hollow fiber type module membrane is from 3 to 4 or less.

The study has been done to examine how FI/SDI varies as different feed water is applied, and how varied operational condition gives an effect to those values.

#### *Methods*

FI values were measured by filtering the subjected water through a membrane filter (made by ADVANTECH) with average pore size of 0.45-micron and diameter of 47mm.

FI/SDI is calculated as follows:

$$FI/SDI_t = (1 - T_i/T_f) \times 100/T$$

Where:

T = Total elapsed flow time, minutes (e.g. 15 minutes for an SDI<sub>15</sub>)

T<sub>i</sub> = Initial time required to collect 500mL of sample

T<sub>f</sub> = Time required to collect 500mL of sample after test time, T (15 minutes for SDI<sub>15</sub>)

In MBR operation, it is possible to fluctuate mixed liquor concentration in nitrification tank. As setting solid retention time (SRT) longer, required mixed liquor volume could be reduced. However, in order to minimize power consumption, there is a move for shortening SRT recently. Therefore, the study was done on MBR permeate from various operating conditions, summarized as follows:

Table 6. Summary on FI/SDI Study Method

MBR Permeate	Description
Raw Wastewater Characteristic	Domestic Wastewater
Utilized Membrane in MBR	KUBOTA Submerged Membrane
Recycle Ratio	4Q
Operational Flux	0.5 to 0.7 m <sup>3</sup> /(m <sup>2</sup> *d)
Operational Conditions	<ol style="list-style-type: none"> <li>1. SRT 300 days or more, MLSS 15,000 mg/L</li> <li>2. SRT 120 days, MLSS 13,000 mg/L</li> <li>3. SRT 10 days, MLSS 5,000 mg/L</li> <li>4. SRT 2 days, MLSS 2,000 mg/L</li> </ol>

For comparison reference purpose, FI/SDI values on secondary effluent from domestic Wastewater Treatment Plant (WWTP), MBR permeate at grey water recycling system, and tap water were examined.

### Results

According to the test performed on permeate from submerged membrane bioreactor, results are summarized in the following table, Table 7. The table also summarizes FI/SDI values examined on secondary effluent from domestic WWTP, MBR permeate at grey water recycling system and tap water.

Table 7. Results from FI/SDI Studies on Various Feed Water

Subjected Water	H <sub>2</sub> O Temp.	Turbidity	Average FI Value	COD <sub>Mn</sub>
	( °C )	(NTU)	(-)	(mg/L)
MBR 1 (SRT: 300 days)	21.0	0.11	<b>2.46</b>	5.0
MBR 2 (SRT: 300 days)	18.0	0.10	<b>2.66</b>	4.3
MBR 3 (SRT: 120 days)	10.8	0.10	<b>2.61</b>	8.0
MBR 4 (SRT: 120 days)	11.0	0.10	<b>0.40</b>	8.3
MBR 5 (SRT: 120 days)	11.0	0.09	<b>1.28</b>	7.0
MBR 6 (SRT: 120 days)	11.0	0.10	<b>2.60</b>	8.5
MBR 7 (SRT: 10 days)	21.0	0.10	<b>2.79</b>	7.0

MBR 8 (SRT: 10 days)	17.5	0.10	<b>2.28</b>	9.3
MBR 9 (SRT: 2 days)	14.8	0.17	<b>2.12</b>	14.5
MBR 10 (SRT: 2 days)	13.0	0.17	<b>2.75</b>	26.3
Grey Water-1	23.0	0.12	<b>2.19</b>	2.2
Grey Water-2	22.5	0.11	<b>1.96</b>	2.6
Conventional	17.0	0.82	<b>6.47</b>	9
Tap Water	11.0	0.09	<b>3.42</b>	1

MBR permeate of domestic wastewater has the average FI/SDI value of 2.5. Moreover, almost all the turbidity of MBR permeates is 0.1 NTU. COD result for MBR permeate with SRT of 2 days was larger than others because of low MLSS concentration which declined biological treatment ability. Consequently, turbidities results are higher for MBR permeate with SRT of 2 days. However, FI/SDI values had no effect by varying the SRT length, and the values are very similar to that of tap water. In addition, secondary effluent from conventional domestic WWTP has FI/SDI and turbidity values of 2.5 times and 8 times greater than those of MBR permeate respectively. Thus, it is concluded that KUBOTA MBR permeate is guaranteed to be suitable RO feed water.

### **Oversea Reclamation Application Study**

In 2000, the City of San Diego has evaluated Membrane Bioreactor (MBR) technology and its potential application to wastewater reclamation. The city plans to recycle 20,000 m<sup>3</sup>/day out of 900,000m<sup>3</sup>/day of advanced primary effluent by treating with RO membrane system. The city has evaluated MBR performance if it can be a viable treatment to be followed by RO treatment.

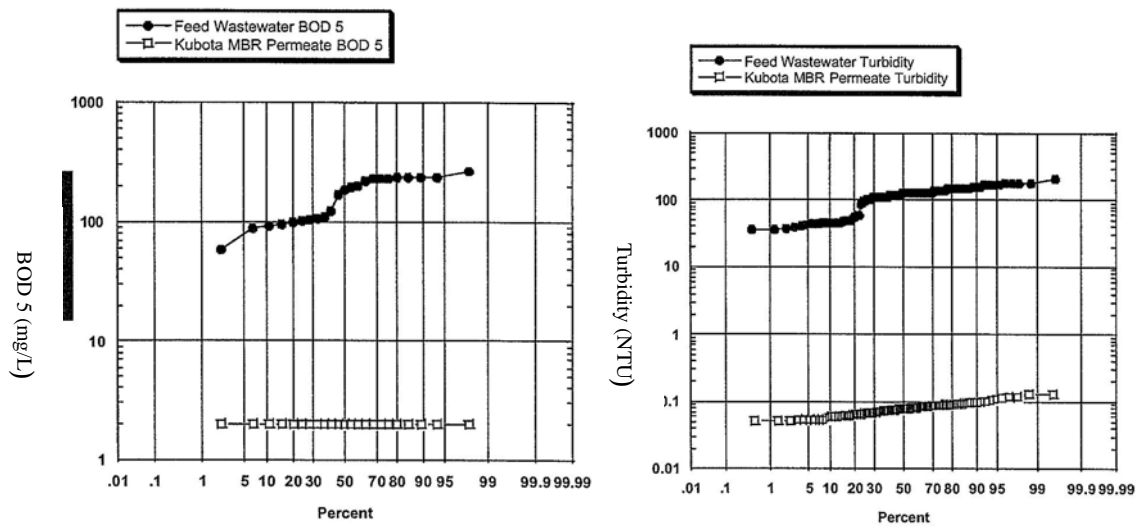


Figure 6. Probability Plot of Organic Removal and Turbidity Removal

Table 8. Effluent Quality at MBR Performance Experiment

Parameters	Effluent
Design Flow	96 m <sup>3</sup> /day
BOD	1-2 mg/L
SS	< 1 mg/L
T-N	2-5 mg/L
T-P	< 1 mg/L
NTU	<0.2 mg/L
SDI	2
e-coli	< 10/100mL
Total Membrane Area	160 m <sup>2</sup>
Volume of Membrane Tank	97 m <sup>3</sup>
Average Flux	0.6 m <sup>3</sup> /(m <sup>2</sup> *day)

The study has concluded that Kubota MBR pilot system produced effluent with turbidity less or equal to 0.1 NTU in 95% of all samples and less than 0.2 NTU throughout the pilot testing and excellent organic removal was achieved. It has also concluded that the Kubota MBR pilot system was capable of producing excellent quality effluent water suitable for use by an RO system.

## Conclusion

In conclusion, after thirteen years of practical MBR installation experience in various wastewater treatment fields in Japan as well as overseas, it is expected there will be more and more needs in water reclamation systems. Submerged Membrane Unit normally produces high quality permeate with non-detectable SS, less than 5mg/L BOD

and less than 0.1 NTU turbidity, which can attract various users. In addition, FI/SDI of KUBOTA submerged membrane permeates is proven to be suitable as RO feed water. Therefore, KUBOTA Submerged Membrane Unit should be an answer for more stringent discharge limit be implemented and chronic water shortage around the world.

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