Update Application of Membrane Technology in Water Environment

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1. Introduction

Current topics related to membrane technology under the recent water environment are as follows:

- Cryptosporidum Outbreak
- Integrity Control System
- Water re-use - Recycle Society
- Biotreatment and Membrane
- Slurry or Sludge Treatment

I would like to introduce the actual examples regarding water re-use, mainly on the above 5 topics.

2. Cryptosporidum Outbreak

Cryptosporidium has been responsible for a number of outbreaks throughout the world in recent times. This has promoted the water industry and regulators to initiate research and monitoring programs in an effort to understand the occurrence of the organism and how to prevent it entering water supplies.

The Ogose outbreak in Japan in which some 8,000 residents became ill from Cryptosporidiosis, has prompted the Japanese Ministry of Health and Welfare to issue an interim regulation on filtration plant turbidity as well as other measures to prevent and control any outbreaks.

In a study carried out at Azabu University in Japan, and funded by the Ministry of Health and Welfare, seeding trials were performed on two membrane samples one MF (nominal pore size 0.25 micron) and one UF (13,000 Dalton). Both membranes were challenged at up to 10^6 oocysts per litre and achieved rejections of >7 log. The MF was challenged at even higher levels, up to 10^8 per litre and still achieved >7 log, although some oocysts were detected in the filtrate at these challenge levels. These rejections exceed even the most stringent proposed regulations for Cryptosporidium removal of 6 log.

Ministry of Health and Welfare has supporting the fund to install membrane equipments for drinking water treatment.

Specifications of Membrane Filtration Unit – Asuke Town, Aichi Pref.

1. Membrane Process Unit

Capacity :	1,200 m^3/day
Membrane area:	900 m^2 (450 m^2/set)
Set :	2 sets
No, of Module:	60 (30 module/set)
Flux:	1.3 m^3/m^2/day

2. Membrane Specifications

Membrane Material:	Polypropylene Hollow Fiber
Pore Size:	0.2 micron
Surface Area:	15 m^2/module
Filtration Method:	Dead End
Cleaning:	Air Backwash

3. Integrity Control Process of Memcor[1)]

There are three key steps to achieve control of system integrity:

a. Monitor integrity using the pressure decay test (PDT) or diffusive air flow (DAF) tests;

b. Identify leaks using sonic analysis; and

c. Isolate faulty modules using the module isolating valves for later repair.

Both the pressure decay and the diffusive air flow test rely on the principle of the membrane bubble point.

3.1 Membrane Bubble Point

The nominal pore size for the MEMCOR microfiltration membrane is 0.2 micron. Liquid in pores of these dimensions are subject to significant capillary forces and a relatively high pressure of air is required to overcome these forces and to push liquid out of the pores., Capillary theory indicates that the air pressure required to force liquid from the pores is inversely proportional to the pore diameter. Thus, the larger the pore the lower the pressure required to displace the liquid.

If air is applied to one side of the membrane and the pressure slowly increased, then air will break through first at the pore with the largest diameter. This pressures is known as the bubble point. The bubble point of the MEMCOR microfiltration membrane is in the range of 200 to 250 kPa.

At air pressures below the bubble point, there will be no air flow through an integral membrane other than a small flow due to diffusion through liquid in the membrane wall. In contrast, the air flow through defects such as a leak through an O-ing seal or a broken fiber, is comparatively large. This feature of membrane is exploited by the both the PDT and DAF systems in order to accurately characterize the integrity of the CMF system.

3.2 Pressure Decay Test (PDT)

Pressure decay testing is performed by applying air at a pressure below the bubble point to one side of the membrane, isolating, then measuring the decline in pressure over time, as shown in Figure 1. The test takes about 5 minutes to perform.

One significant advantage of the PDT test is that it requires no additional equipment. The air supply, valves and pressures monitors are all present as part of the CMF system. This enables the test to be conducted automatically by the control system, including logging of the test result and generating an alarm if the result is outside limits.

3.3 Diffusive Air Flow (DAF) Test

The DAF test is fundamentally similar to the PDT in that they both measure air flow through defects during the integrity test. However, rather than measure air leakage as a pressure decay rate, the DAF test does this by filling the shell of the module with liquid and allowing the air leakage to displace liquid from the shell, as shown in Figure 2. The flow rate of displaced liquid is then a direct measure of the membrane integrity.

The main advantages of the DAF test over the PDT are that it tends to be less sensitive to any external air leaks, is easier to measure accurately than pressure decay, and diffusion of air through liquid in the membrane wall contributes to a lesser extent. The combined effect is that the DAF test tends to more sensitive to changes in integrity than the PDT test. The trade-off for the increased sensitivity is that, although readily automated, the DAF test requires some additional pipework and fittings in order to measure the displaced liquid flowrate.

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3.4 Sonic Analysis, Module Isolation and Repair

Having identified a change in system integrity that requires action the next step is to identify and isolate the module that contains the leak. This is achieved using a MEMCOR Sonic Analyzer.

The analyzer is a sensitive listening device tuned to the sound made by bubbles escaping through fiber defects or other sources of leakage. Air at a pressure below the bubble point is applied to one side of the membrane and the analyzer is held against the outside of the module. Air leaking through defects creates a distinctive sound that can be picked up by the device and is displayed as a sound level on the front of the unit.

Modules identified in this way can then be isolated using the in-built module isolation valves on the top and bottom of each MEMCOR CMF module, and later removed and repaired on site. This involves placing the module inside a housing, applying air external to the fiber bundle and looking for bubbles escaping from the end of leaking fibers. The fiber is then permanently sealed using a stainless steel pin.

4. Subjects of Water Environment in Japan

Summarizing the usage of water in Japan as follows;

(1) Usage ratio of water resources is approx. 21%.

(2) Water Consumption for Agriculture and Industrial uses remains on the same level while the quantity of City Water tends to increase.

(3) Recycling ratio of Industrial Water stays around 70% level.

As recent environmental problems under the current water balance, following subjects have been taken up:

(1) Declining of Maintaining and Infiltrating Rainwater due to Lowering Conservation of Forests and Urbanization

(2) Contamination of Rivers, Lakes and Marches due to delayed Sewage Equipment installation against Increasing City Water

(3) Contamination of Water Resources due to new Germs and Organic Solvents

Various countermeasures have been taken up by various private companies and governmental agencies in order to solve these problems and to lighten its burden to the environment.

As one of the countermeasures, I would like to introduce Advanced Treatment of Industrial Waste Water Using Membrane Separation Technology and Its Process How to Settle its Problem.

4.1 Sony Factory

As recycling case of Industrial Waste Water by advanced treatment, I would like to introduce Waste Water Recyling System developed by Sony Mizunami which is manufacturing TV Braun Tube. They are using service water as their washing water through their purifier and installed two kinds of processing facilities; organic and oxidizing ones to treat waste water. They planned to recycle organic waste water because their location is distinguished as drought area and their water cost is high. It also is said that reducing environmental burden happened by waste water is one of their purposes since they have obtained Environment ISO.

Figure 3 and Table 1 are shown the flow chart of Waste Water Recycling System and its facility specification. The treatment method is the combination of MF Membrane and RO Membrane and each feature of these membranes and system are followed:

Figure 4 is shown the change of electrical conductivity which shows recycling water quantity and dissolved ion quantity recorded during two years' operation. It is seen that the stable supply of recycling water is obtainable even its quantity is increased two times by accelerating this facility one year after starting its operation. It is also shown that the stable quality which is equivalent to purified water is expected even the raw water is varied from time to time.

In parallel with technological point, economical usage of this system were big subjects on this stage. Running cost covered èlectrical, chemical and membrane exchange fees. Specially, membrane exchange fee accounted for the most of these fees. However, since the system becomes stable, this exchange timing is becoming one time or less in three years. Thus, recycling cost becomes less than 100 yen/t which is much cheaper than supply water. This means that they succeed to reduce the water cost largely. In conclusion, it is said that Membrane type Waste Water Recycling System can produce the recycled water which is clarified to purified water level and with less cost than city water.

Sony Mizunami, introducing this system, succeeded to reduce 1/4 of their total waste water and lightened their environmental burden.

Based on Sony Mizunami's performance, Sony Display Device Singapore is introducing the similar waste water recycling system. Singapore is presently relying on Malaysia to send their 50% of total water resource. To ensure national security, Singapore aims the 100% self-sufficing by the beginning of 21st century. As their countermeasures, they are developing Sea-water Freshening Facility and its Waste Water Recycling. The above Sony is a pioneer of this facility.

Water Recycling Promotion taken on the national level is only proceeded in the small country like Singapore, the burden to its environment caused by the waste water will be dramatically reduced. Table 2 shows the comparison result between PUB Water (Industrial Water) and RO treated water.

4.2 Re-use of Washing Waste Water

Recycling System is remarked recently due to reinforced Waste Water Regulation and saving of water costs. Basically, it is a main stream to clarify the waste water using Sand Filtration+Activated Carbon+Chlorinated Sterilization. This method contributes to get through various waste water regulations such as BOD (Bio-chemical Oxygen Demand) and COD (Chemical Oxygen Demand) and to save service water and sewage costs. However, no one have found out its suitability as Washing Water.

Under the circumstances, Karube Clean introduced Recycling System using Sand Filtration+Ozone 3 years ago. By this system, daily water consumption becomes approx. 200 tons and 2-months service water and sewage costs are reduced from 3.6 million to approx. 0.4 million Yen (sewage is discharged to the sea). Though BOD, COD and SS (Suspended Solids), etc. are largely removed, Ion substances like Natrium, Calcium Magnesium remain as they are. Once recycled this water, the alkali substance is cauterized and odour are produced which are becoming new claims. Furthermore, SS stays in filter media which requires cleaning work. After all, it is required to mix this water with service water and the merit of saving costs lessened.

Following is the explanation of the Waste Water Recycling System which is developed at this time:

After biological treatment, remove larger hairs and fibers than 78 micron by using spin-filter. Then, remove SS and algae by MF membrane which completely removes larger substances than 0.2 micron. Followed by MF membrane, remove COD, colour and salts by RO Membrane. At the final treatment, remove odour and colour particles by ozonation, and return to a water tank. (Figure 5 RO and MF Membrane Units)

Table 3 shows Water Quality analyzing results before and after the MF and RO Membranes Treatments. After RO Membrane Treatment, electrical conductivity becomes 26.8 ms/cm and each ion like Na, K Ca is largely removed. Considering that electrical conductivity of service water is 200 ms/cm on average, this water is considered completely purified water. SS (Suspended Solids), COD and BOD are almost equivalent to 0 (Zero).

Separation Membranes such as MF and RO are already introduced in general plants and those durability's are well ensured. Maintenance technology such as air-washing and chemical washing is established. Thus, selecting a membrane suitable to cleaning waste water and arranging the system to adequate to a plant are the part of know-how. The total cost required for the facility is 45 million Yen and monthly setting cost of service water and sewage is 1.7 million Yen in case of Karate Clean.

The introduction of this system is planned at 10 locations, mainly in linen factories which have large quantity of waste water.

4.3 Gray Water

The usage of Gray Water is to recycle the lower-quality water compared with city water; i.e. sewage, recycled-water of industrial waste water, rain water for the use of flush toilet, coolant, air cooling, water sprinkling, etc. (Figure 6 Gray Water Usage System)

The purpose and effectiveness of this gray water are following;
(Refer to Table 4 Raw Water Quality and Targeted Quality of Gray Water)

- Reducing the consumption of city water by using these recycled water and rain water. This becomes the one relieving method of suppy-demand unbalance in water-lacking area.
- Lightening sewage burden by reducing the waste water quantity and turbidity burden and contributing to water quality control in public water area

- Influencing favourably the promotion activity of using water resources efficiently as saving water method in urban areas

- Relieving the city water restriction for the people who use gray waste waters.

There are three systems to use gray water under the volume of the consumption; Individual circulating system within a used building such as an office building; Local circulating system used cooperatively among several buildings within urban development areas and or among assembled houses developed on a large scale; Large-area circulating system used on a large extent after being supplied from sewage treated place and/or industrial water.

In the latter half of 1955, this system was introduced in Japan. After that, the usage of this system has been gradually increased. Around and after 1980, the usage has been drastically increased because of the drought happened in many areas, specially in Fukuoka in 1978, energy saving policy in the first half of 1975 and instructions from government and local agencies to promote the gray water under the said background. Recently, in average 130 cases are recorded to introduce this system annually, mainly in water-lacking areas. At the time of 1993, this system is used in 1,963 facilities through Japan. Daily consumption is expected 277,000 m3 in total which is equivalent to 7% of total living water consumption. (Please refer to Table 5 Usage Situation by Gray Water Circulating Systems and Table 6 Example of Individual Circulation System)

I am herein summarizing the test result of Gray Water Treatment using Memcor as shown in Table 7 (Kurabe Process). By this process, the required cost is reduced up to 1/3 - 1/5 compared with the currently used membrane system.

4.4 Advanced Treatment of Pig Farm Waste Water

Agricultural water accounts for 1/2 of total water. Most of the water is used for paddy field just once and less burden to the environment. On the contrary, pig farm waste water is influencing on the raising agricultural crops due to spreading the high-concentrated water to the farms. Because of this reason, this water is discharged after processing under biological treatment. I would like to introduce this advanced treatment.

In Sato Pig Farm, as shown in Figure 7, they completed the Local Circulating System which recycles the urine from piggery to purified water and produces the compost in Fermenter by using excrement from piggery. This facility is composed of two units: the first treatment of biological process and advanced treatment using membranes and ion-exchanger. MF membrane separates the turbidity ingredient and RO membrane does organics and each ion solved. The purified water is obtainable at this stage. As a part of volatile ammonia nitrogen is leaking through this RO membrane, this is completely removed through the ion-exchanger. Table 8 shows the quality of processed water.

The current problem of this system is how to reduce the concentrated waste water produced under this waste water treatment and to reduce the back water to Fermenter in order to maintain the balance of whole system. This concentrated water is produced through RO membrane. As RO membrane only permeates the water due to its reverse osmosis, dissolved matters are concentrated on the surface of the membrane. As a result, low solubility ingredient like SiO2 is produced scaling and both water quality and quantity is declining.

The water used for this process is ground water and contains lots of SiO2. Thus, possible recycling rate by RO membrane is 50%. Choosing the proper scaling protection agent, it is possible to maintain over 70% recycling rate and the balance of the whole system.

5. Membrane Bioreactor

The membrane bioreactor consists of a biological reactor integrated with a microfiltration.

Membrane modules are submerged in the aeration tank, and air bubbles are cleaning the membrane surface. (Figure 9 MBR)

Characteristics of MBR are:

1) Characteristics of MBR

- SRT (or sludge age) independent of HRT
  - Allow old sludge age and high MLSS
- Minimum sludge wastage
- No sludge settlement problem

2) Target Water Quality

- BOD (<10 ppm) & COD (40 ppm)
- Ammonia (<2 ppm)
- O&G (<5 ppm)
- Suspended Solids (<1 ppm)
- Coliforms (<100 cfu/100 mL)
- Turbidity (<1 NTU) & Colour

3) Key to MBR

- Module tolerant of high MLSS
- Efficient air scrub and b/w
- Integrity test
- Easy CPI

4) Effect of MBAR

- Primary settlement tanks and facilities
- Clarifiers
- Tertiary stage, e.g.. sand filters
- Reduced tanks size and plant space
- Reduced recirculations and pipe size
- High quality effluent
- Chemicals for flocculation and settlement

Many actual MBA are operating in Japan.

6. New Concepts adopting Membrane Technology for Sludge/Slurry Concentration Systems

6.1 CMP (Chemical Mechanical Polishing of Semiconductor) Waste and Recovery

Recently Chemical Mechanical Polishing (CMP) has been taken close-up as a new planatized technology corresponding to integration and being compact of semiconductor devices. We consider that CMP technology is applied for various process which requires the planation on every LSI production process and the number of CMP equipment will be increased.

CMP, being paid high attention from every field, has a lot of problems which should be solved; i.e. high running cost, necessity of choosing polishing material, low speed of polishing. Especially, regarding polishing material, as it is required high purity, the material is expensive and it is said that polishing material accounts for 1/3 of the total CMP process cost.

However, under the present circumstances, polishing material slurry is treated as sludge and disposed as industrial waste. This is a great loss from economical view point and in view of saving natural resources.

Ceramics membrane is applied for re-cycling system of polishing slurry, as a first step in order to cut industrial waste.

The system we are currently developing is to filter the above-mentioned polishing slurry by using our MEMBRALOX ceramic filter, to concentrate them up to 10 times of its density and to collect them.

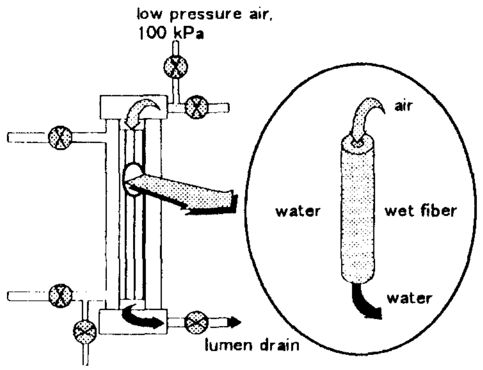
6.2 New MAC 21

Concentration of backwash waste water discharged from sand filter in drinking water facility.

- 200 - 2000 m^3/d

Literature:

[1] W.T. Johnson : AWWA 1997



Step 1:
Air is drained from the lumen of the fibre using air at a pressure below the bubble point, typically 100kPa.

Figure 1a: Lumen Drain

Step 2:
The lumen is pressurised to 100kPa,isolated, and the pressure decay rate is monitored. Shell side is vented to atmosphere.

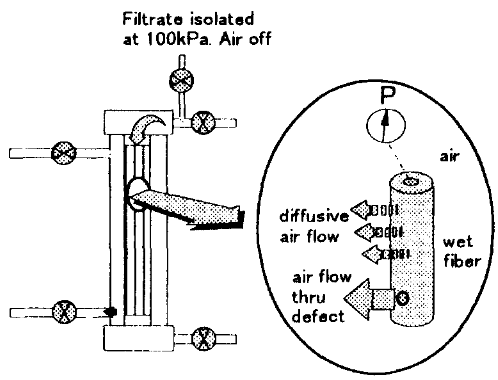
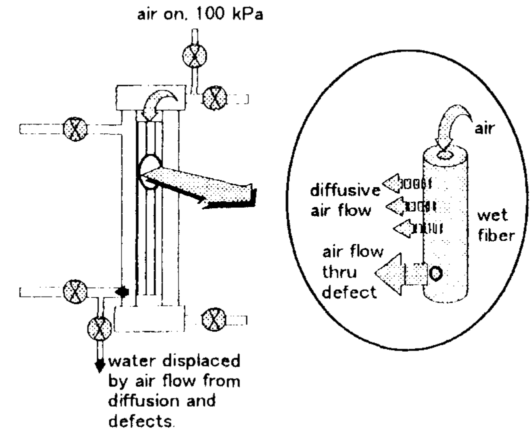


Figure 1b: Monitoring Pressure Decay Rate



Step 1: Lumen drain

Step 2: Pressurise to 100kPa and maintain at this pressure using a pressure regulator. The shell side remains isolated.

Step 3: Open small shell side valve through which the displaced liquid can flow. The liquid flowrate can be measured using a stopwatch and measuring cylinder or automated by timing the liquid rise between two points in a tube.

Figure 2 DAF Test Procedure

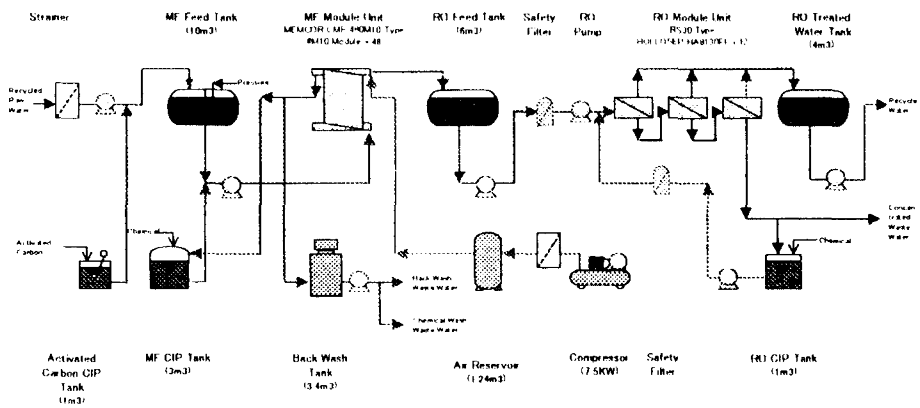


Figure 3 Flow Sheet of Mizunami Factory

		MF Membrane Unit	RO Membrane Unit
Quantity treated		730 m3/day	540 m3/day
Maker		Memtec Japan Ltd.	Toyobo Co., Ltd.
Unit Type		MEMCOR CMF480M10	HOLLOSEP RS30
Membrane	Model	M10	HOLLOSEP HA8130FI
	Material	Polypropylene	Cellulose Triacetate
	Form	Hollow Fiber	Hollow Fiber
	No. of fibers	48	12
	Structure	1 (One) stage	3 (three) stages tree-type
Supplying Pressure		100 KPa	2 MPa

Table 1 Specification of Industrial Waste Water Recycling System

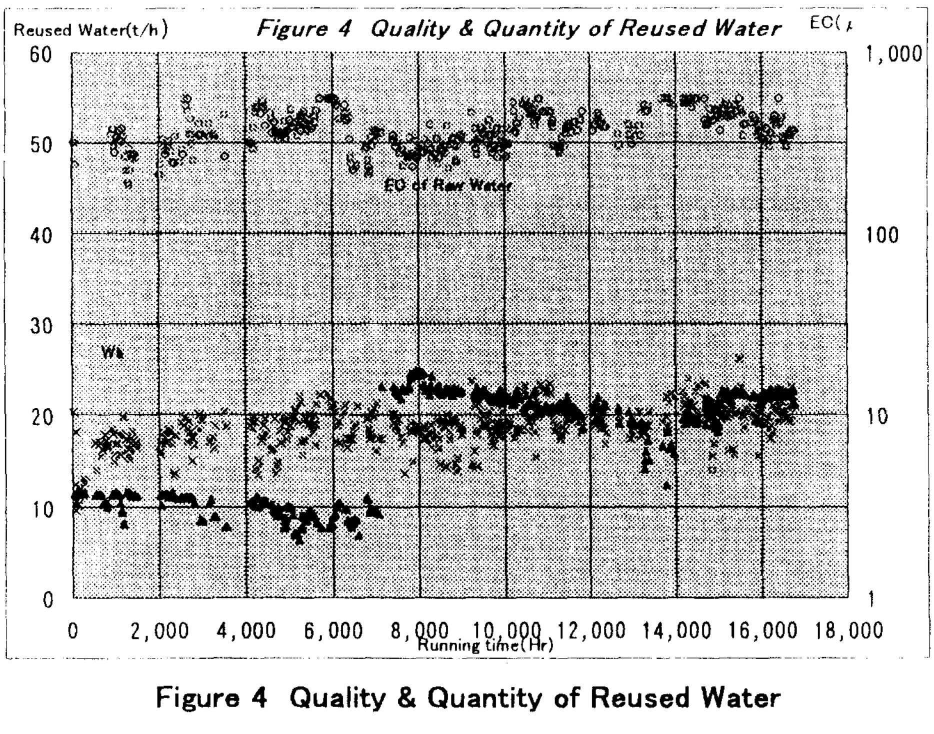


Figure 4 Quality & Quantity of Reused Water

Results in milligrams per litre

Test \ Sample	PUB Water	RO Treated Water
	11-May	11-May
Colour (Hazen Unit)	<5	<5
Turbidity (NTU)	0.2	0.1
pH Value	6.8	6.5
Conductivity at 25℃ us/cm	236	94
Total Dissolved Solids	125	50
Nitrate Nitrogen (as N)	0.4	0.5
Free Ammonia (NH3)	0.4	<0.1
Fluoride (F)	0.4	0.2
Total Alkalinity (as CaCO3)	22	20
Total Hardness (as CaCO3)	46	4
Chloride (Cl)	36	13
Sulphate (SO4)	22	<1
Phosphate (PO4)	<0.01	<0.01
Silica (SiO2)	1.8	0.2
Iron (Fe)	0.02	<0.01
Manganese (Mn)	0.01	<0.01
Copper (Cu)	<0.01	<0.01
Aluminium (Al)	0.03	<0.01
Total Solid Residue	-	-
Chromium (Cr6+)	<0.05	<0.05
Lead (Pb)	<0.01	<0.01
Sodium (Na)	-	-
COD (Cr)	2	<1
Total Organic Carbon	1.5	0.6

Table 2 Comparison of Water Quality

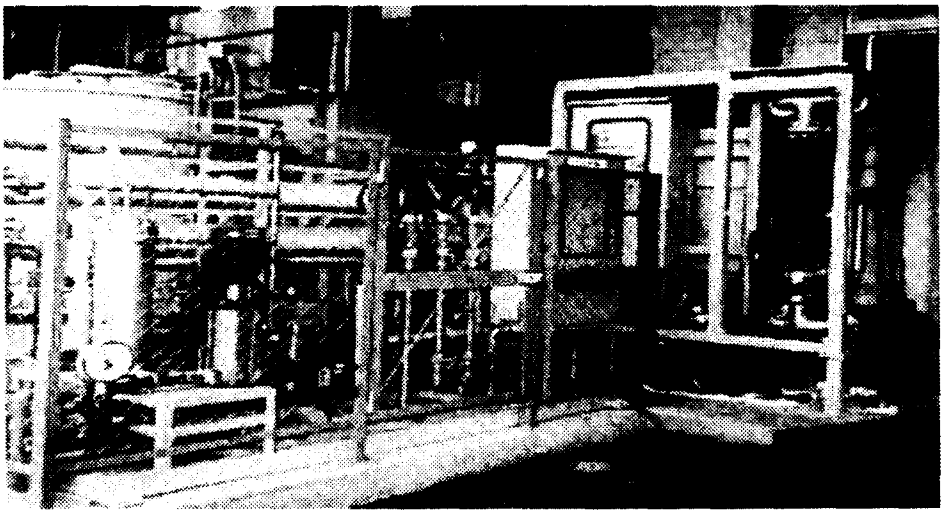


Figure 5 RO and MF Membrane Units

Item	Unit	Raw Water	MF	RO
Electrical Conductivity	ms/cm	897	940	26.8
Cation				
Na	mg/l	216	216	4.38
K	mg/l	10.1	9.36	0.12
Ca	mg/l	13.6	13.2	0.24
Mg	mg/l	3.23	3.20	0.05
Total	mg/l	243	242	4.79
Anion				
Cl	mg/l	78.6	70.3	2.04
HCO3	mg/l	401	390	7.93
NO3	mg/l	22.5	20.1	0.48
SO3	mg/l	86.0	85.4	<2.0
Total	mg/l	588	566	10.5
SiO2	mg/l	74.4	81.3	2.60
Fe	mg/l	0.05	0.04	0.01
Mn	mg/l	<0.01	<0.01	<0.01
Total Evaporated Residue (TDS)	mg/l	812	804	17.9
Suspended Solid (SS)	mg/l	14.0	<2.0	<2.0
COD (Mn)	mg/l	4.5	4.0	<0.5
BOD	mg/l	5.0	5.8	<1.5
TOC	mg/l	36.8	31.0	1.22
pH		8.0	8.7	6.18

Table 3 Water Quality for Washing Waste Water

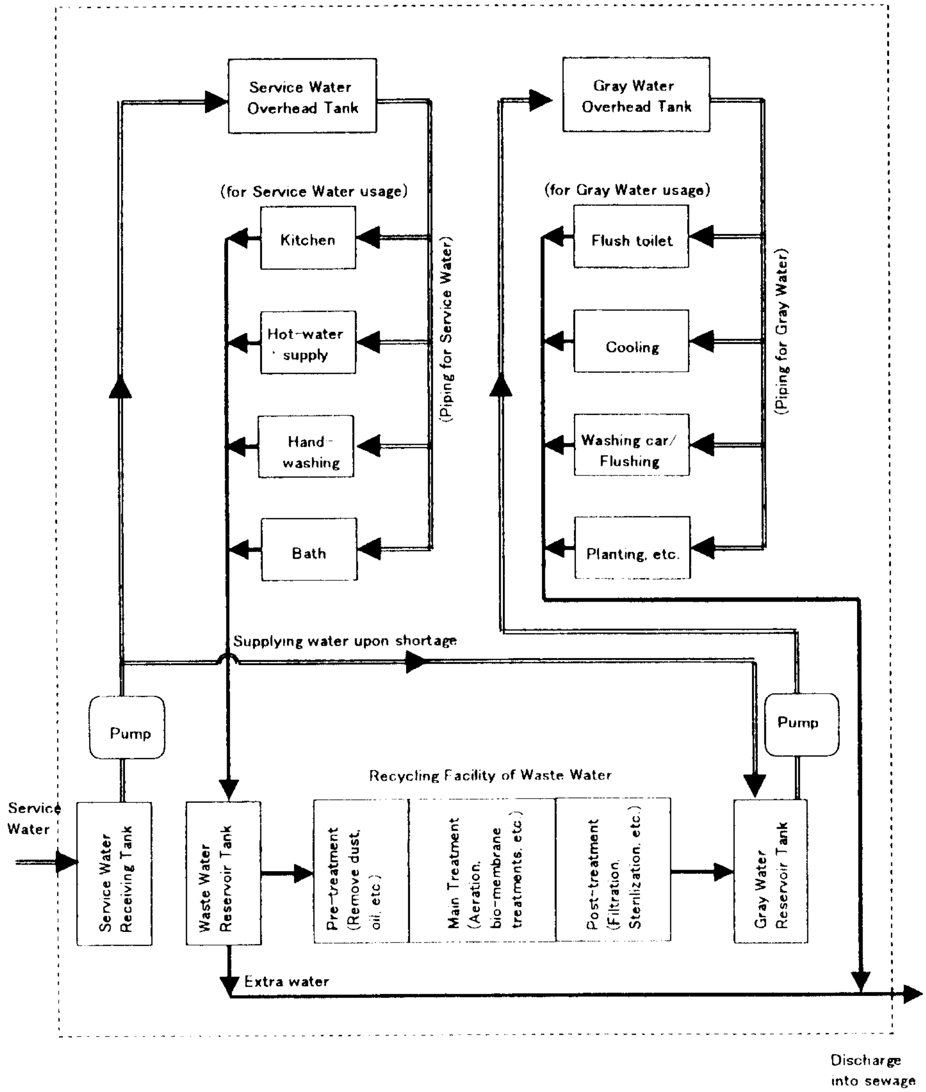


Figure 6 Gray Water Usage System

	Raw Water	Gray Water	Remarks
Temperature	below 40℃	below 40℃	
pH	5.5 ~ 8.0	5.5 ~ 8.0	
Odour	-	No discomfort odour	
Colour	-	No discomfort colour	
SS	100 - 200 ppm	below 10 ppm	
BOD	100 - 200 ppm	below 10 ppm	
COD	100 - 200 ppm	below 30 ppm	
ABS	5 - 10 ppm	below 1 ppm	

Table 4 Raw Water Quality and Targeted Quality of Gray Water

Investigated in 1994

System	No. of Areas	No. of Facilities	Daily Consumption (m3/D)
Individual Circulating System	-	1,267	139,794
Local Circulating System	57	179	68,095
Large-area Circulating System	36	517	69,475
Total	-	1,963	277,364

Researched by National Land Agency

Table 5
Usage Situation by Gray Water Circulating Systems

Site	Re-use Purpose	Usage quantity planned	Starting date
Yuraku-cho Marion	Flush-water, etc.,	741 m3/day	October 1984
Fukuoka Daido Seimei Building	Flush-water	35 m3/day	May 1987
Nagoya City Gymnasium	Flush-water, sprinkling	864 m3/day	August 1987

Table 6 Example of Individual Circulating System

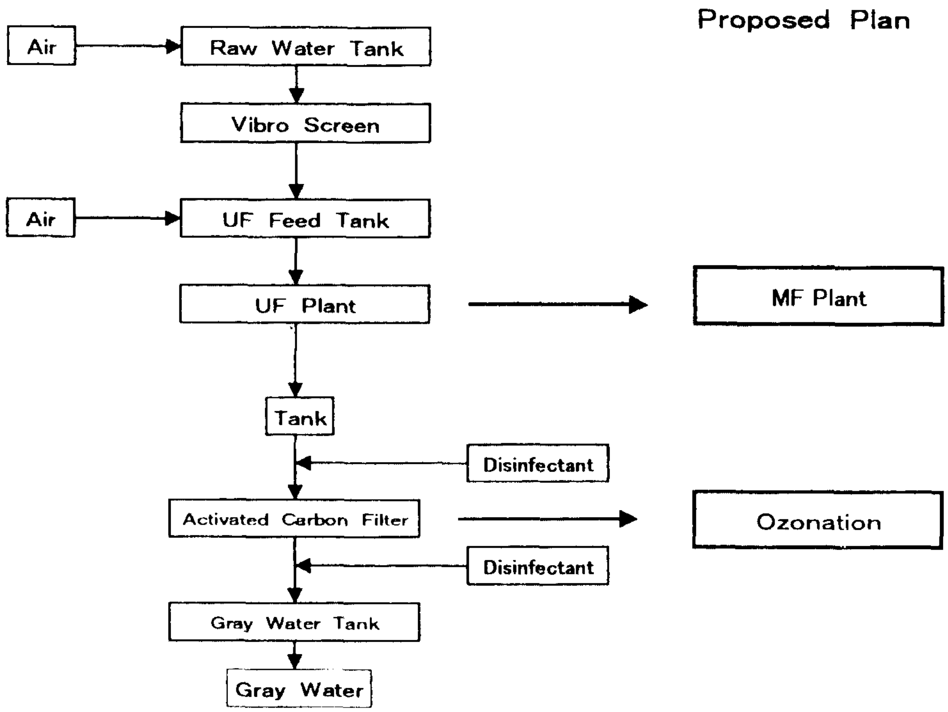


Figure 7 Gray Water Equipment

Testing No.		MF Raw Water	MF Filtered Water	Ozone Treated Water	Calculating Method
pH		6.8	7.0	7.1	JIS K 0102 12.1
SS	mg/l	39	Under 1	Under 1	JIS K 0102 14.1
COD	mg/l	22	8.4	7.9	JIS K 0102 17
BOD	mg/l	22	Under 1	Under 1	JIS K 0102 21-32.3
Anion surface-active agent	mg/l	0.32	0.31	0.13	JIS K 0102 30.1
Colour degree	degree	52	22	7	JIS K 01[illegible] 10.1

Table 7 Kurabe Process

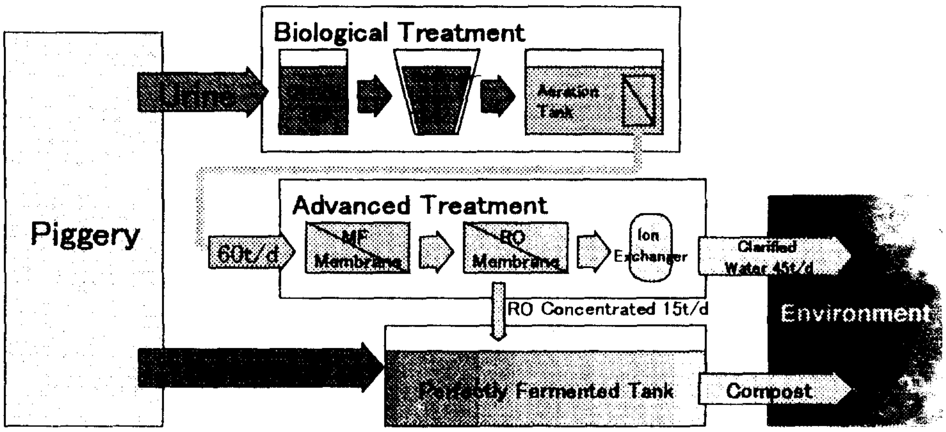


Figure 8 Local Circulating System in Pig Farm

Item		Raw Water	!st Treatment	Advance Treatment
Water Quantity	t/day	60	60.0	45.0
TDS	mg/l		4,010.0	13.0
pH			6.5	6.6
COD (Mn)	mg/l	18,000	208.0	<0.5
BOD	mg/l	18,000	54.4	1.1
Colour	degree		130.0	<1.0
Total N	mg/l	2,000	82.4	0.2
Total P	mg/l		159.0	<0.1

Table 8 Qualilty of Processed Waste Water at Pig Farms

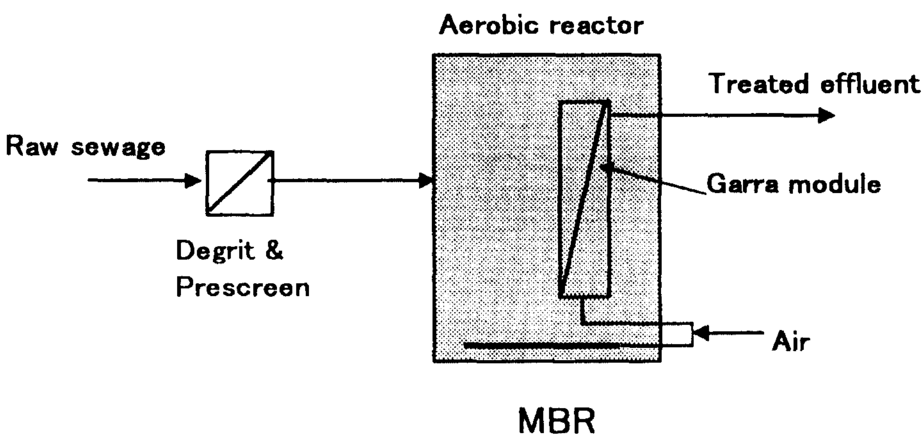


Figure 9 MBR