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The membrane application on the wastewater reclamation and reuse from the effluent of industrial WWTP in northern Taiwan

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Abstract

This is the first full scope study of wastewater reclamation and reuse on public WWTP in Taiwan. A 50 m^3/day pilot plant with membrane and biological systems of wastewater reclamation has been deployed and operated in the WWTP of Hsinchu Industrial Park, northern Taiwan. The reclaimed water has been transported to five factories and been used as the fresh water supply as well as the makeup water of cooling tower. The future construction of a 10,000 m^3/day wastewater reclamation plant has been proposed and financially investigated. The business plan of BTO is proposed for future development. The 50 m^3/day pilot plant consists of a membrane UF/RO system followed by the systems of high efficient biological oxidation systems BioNET and/or BAC. The bench-scale membrane scaling/fouling test and magnetic anti-scaling system are also introduced to verify the mechanisms of membrane scaling and fouling. The result of the pilot study shows that the reclaimed water can conform the drinking water standard and can be used as the make-up water of cooling tower as well as the manufacturing water of many industrial applications. The concentrate of RO process can fit the effluent standard and can be discharged directly to the river nearby. There are 88.6% of the factories in the industrial park express their willingness of using reclaimed water and 4600 m^3/day is requested after the preliminary poll. The cost of reclaimed water is around US\$0.54/m^3 (including construction, O & M and transportation) which is higher than the tariff of tap water (US\$0.27/m^3) but lower than the cost of seawater desalination as well as that of reservoir construction. Under BTO business plan, a wastewater reclamation plant of minimum 10,000 m^3/day is proposed in order to make profit for future operation.

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Keywords: Industrial wastewater reclamation; BioNET; UF; RO; Membrane scaling test; Reclamation potential; BTO

1. The Hsinchu industrial park (IP)

1.1. Scheme of Hsinchu IP

Hsinchu IP consists of two parts, east and west, which is separated by freeway No. 1. The east part of Hsinchu IP has the area of 226 hectares while the west part has 257 hectares. The electronics, petrochemical, plastics, and machinery are main categories in Hsinchu IP.

1.2. Effluent rate and water quality

The WWTP is located in the west part of Hsinchu IP. The flow rate of the WWTP is around 18,500 m^3/day~22350 m^3/day in 2002. The effluent of WWTP can always fit the effluent standard. (shown as Table 1)

2. Design and deployment of pilot plant

2.1. Process

Three processes have been evaluated to reclaim the effluent of WWTP by introducing the in-situ water quality and operational condition of the WWTP. The way of dealing with RO concentrate is the main difference of these three processes.

Process A: High efficient biological oxidation→sand filtration→Bag filtration→UF (hollow fiber) →RO

Process B: Coagulation→Bobble floatation removal→UF (plate)→RO→Oxidation of RO concentrate

Process C: Sand filtration→Bag filtration→Chemical Oxidation→UF (hollow fiber)→RO

After introducing the evaluating processes of BAT-3E (Best Available Technology—Engineering, Environment and Economy), process A is chosen for the 50 m^3/day pilot plant of wastewater reclamation.

2.2. Flow chart

Fig. 1 is the flow chart of the pilot plant of wastewater reclamation. The effluent of WWTP goes parallelly through two high efficient biological treatment systems, BioNET (Biological New Technology, shown as Fig. 2) and BAC (Biological Activated Carbon, shown as Fig. 3) to remove COD for the sake of lowering COD in the RO concentrate. Two biological systems have been parallel deployed without chemical additive as the pre-treatment to remove 20~50% of the effluent COD prior to the membrane system. Then, the outflow goes through sand filter, bag filter, UF and RO to remove most of the particulates and ions.

2.3. Deployment and operation

A 50 m^3/day pilot plant consists of two parallel biological systems (BioNET and BAC, shown as Photo 1) and a membrane systeom (shown as Photo 2) has been deployed inside the WWTP of Hsinchu IP

Table 1
The effluent water quality of Hsinchu WWTP in 2002

Items (mg/L)	SS	COD	BOD	Cu	Ni	Fe	Zn
Average Effluent water quality	15	44	6	0.30	0.10	0.85	0.39
Effluent standard	30	100	50	3	1	10	5

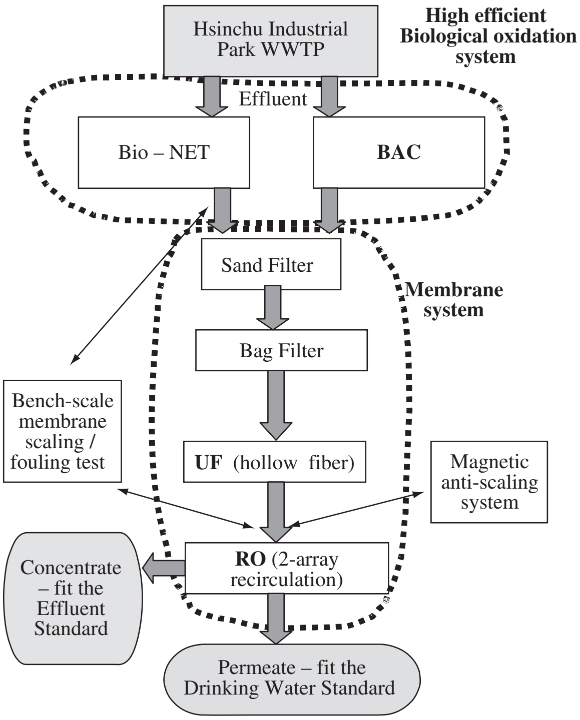

Fig. 1. The flow chart of pilot plant of wastewater reclamation.

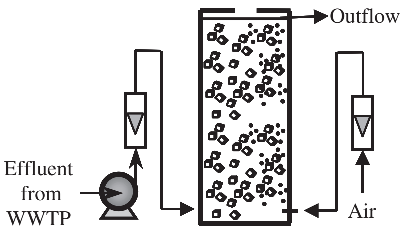

Fig. 2. The concept of BioNET operation.

by August 31, 2003. (Shown as Photo 3). The membrane system consists of sand filter, bag filter, hollow-fiber ultra filtration (UF) and anti-fouling reverse osmosis (RO). The particles of 1–20 μm can be remove prior to UF. The anti-fouling RO can then remove most of the salt ions, heavy metals and organics. The continuous operation begins from September 10, 2003 and more than 6 months' test has been conducted by now.

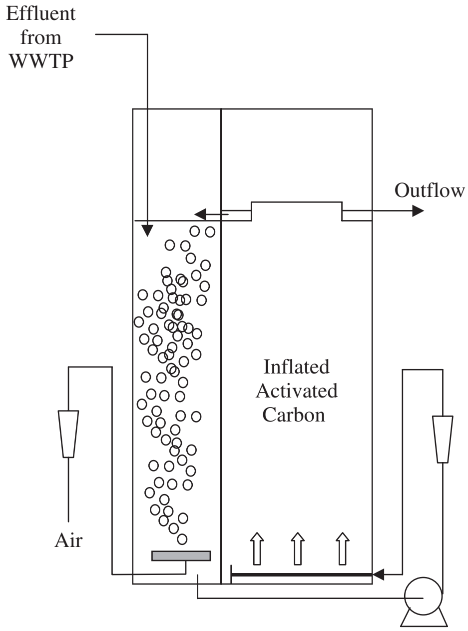

Fig. 3. The concept of BAC operation.

Photo 1. The deployment of two biological systems (left: BAC, right: BioNET) of 50 m^3/day pilot plant in theWWTP of Hsinchu IP.

3. Bench scale membrane fouling test

The facility of bench scale membrane fouling test consists of a stainless chamber with the operation pressure up to 69 bars (1000 psi). The

Photo 2. The deployment of membrane system (from left to right: sand filter, bag filter, UF and RO) of 50 m^3/day pilot plant in the WWTP of Hsinchu IP.

Photo 3. The completion of reclamation system of 50 m^3/day pilot plant in the WWTP of Hsinchu IP.

size of the tested membrane is 14.6 cm × 9.5 cm. The permeate flux (J) is continuously recorded and the water qualities of pH, Zeta Potential (mV), SDI_{13}, color, EC (μS/cm), Turbidity (NTU), Alkalinity (mg/L as $CaCO_3$), Hardness (mg/L as $CaCO_3$), and COD (mg/L) are tested for feed water, permeate water and concentrate water.

Table 2 shows the water qualities of the effluent of WWTP, BioNET and BAC. The color of the effluents are pinkish while the BioNET and BAC show good performance on removing more than 50% COD.

The test shows that the UF process can greatly reduce SDI_{15} (from>6 to –1.03) and the RO membrane is protected. Fig. 4 shows the permeate fluxes of RO with or without the process UF are similar which indicates that very few particles exist in the outflow of bag filter.

Fig. 5 ~ Fig. 7 show the results of SEM (scanning electron microscope) of clean RO surface, RO surface after applying effluent of

Table 2
The Water qualities of the effluent of WWTP, BioNET and BAC

Items	Effluent of WWTP (sample 1)	Effluent of WWTP (sample 2)	Effluent of BAC (sample 2)	Effluent of BioNET (sample 2)
PH	7.7	7.4	7.8	7.6
Zeta potential (mV)	−15.4	−15.1	−14.6	−11.8
SDI_{15}	6.03	6.04	6.02	5.92
Color (pt-co unit)	93	94	89	80
E. conductivity (μS/cm)	3890	3410	3420	3810
Turbidity (NTU)	2.41	3.14	3.09	1.78
Alkalinity (mg/L as $CaCO_3$)	148	130	130	104
Hardness (mg/L as $CaCO_3$)	258	212	210	309
COD (mg/L)	52	69	26	30

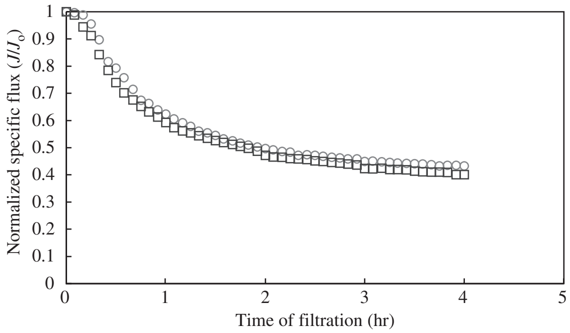

Fig. 4. The influence of UF on permeate flux of RO ○ UF + RO; □ RO only (BW-400FR RO, dow chemical, pressure 9 bars, initial permeate flux (Jo) 10.5 μm/s, avg. recovery 40%, crossflow velocity 10 cm/s, adjusted pH 6).

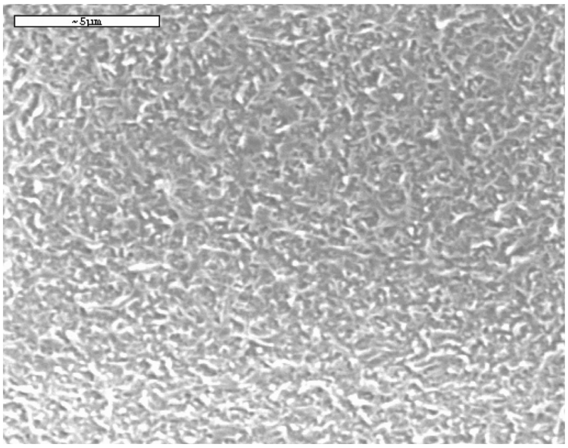

Fig. 5. SEM result of clean RO surface (×6000) EDS analysis of clean RO surface.

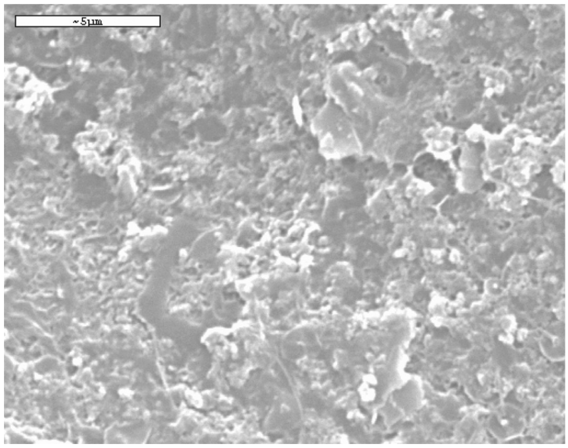

Fig. 6. RO surface by applying effluent of WWTP (×6000) EDS analysis of RO surface by applying effluent of WWTP.

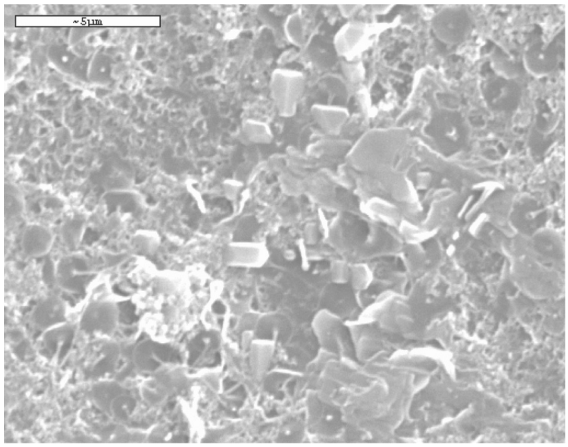

Fig. 7. RO surface by applying permeate of UF (×6000) EDS analysis of RO Surface by applying permeate of UF.

WWTP, and RO surface after applying the permeate of UF. Most of Al, Ba and particulates are removed after UF and only the hardness crystal lies on the surface of RO from Fig. 6, Fig. 7 and the test of EDS (energy dispersive X-ray spectrometer).

Table 3 shows the water qualities of a specific test with the process Bio-NET→UF→RO to treat the effluent of WWTP. Table 5 indicates that RO can remove 100% color, 96.35% E.C., 98.45% Hardness and 85.45% COD for the bench scale membrane test.

The influence of magnetic anti-scaling system (Matic) on membrane test is introduced. The combination of UF+Matic is a better pre-treatment for RO operation according to Fig. 8.

Table 3
The water qualities of the process BioNET→UF[1] + RO

Items	RO feed (BioNET effluent–UF)	RO permeate	RO Concentrate	Rejection (%)
PH	6[a]	5.6	6.7	—
SDI_{15}	0.89	—	—	—
Color (Pt-co unit)	69	0	84	100
E.C. (μS/cm)	3830	139	4640	96.35
Hardness(mg/L as $CaCO_3$)	291	4	396	98.63
COD (mg/L)	22	3.2	35	85.45

UF membrane: (LOP1010, Asahi chemical industry), PAN, MWCO: 80k Daltons.
Operation conditions: pressure 1.5 bars, recovery 100%, Avg. permeate flow rate 1100 mL/min.
[a]Adjusted pH with HCl.

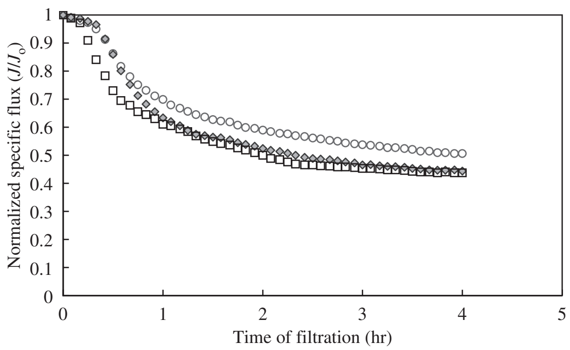

Fig. 8. The influence of UF and magnetic anti-scaling system to RO operation ○ UF + Matic + RO; ◇ Matic + RO; □ UF + RO (BW-400FR RO, Dow Chemical, pressure 9 bars, initial permeate flux (*Jo*) 10 μm/s, Avg. Recovery 40%, Crossflow velocity 10 cm/s, adjusted pH 6).

4. Operation of pilot plant

Four and three test runs are conducted by Bio-NET and BAC pilot tests. Table 4 shows the testing results of BioNET and Table 5 shows that of BAC pilot plants.

The HRT can be as low as 0.48 hrs, volume loading as high as 2.39 kg COD/m^3·day, and COD removal rate 22~29% for BioNET pilot test according to Table 6. The HRT can be as low as 1.20 hrs, volume loading as high as 1.06 kg COD/m^3·day, and COD removal rate 19~29% for BAC pilot test according to Table 5.

The operation of filtration and membrane system is more complicate than the biological treatment system. The pressure differences between the in/out of sand filter, bag filter and UF system in the very beginning of pilot operation are shown in Fig. 9.

The operational parameters of sand filter, bag filter and UF system are modified according to the accumulation or depression of the pressure differences. The RO system is steadily operated for the first half year. Fig. 10 shows that the salt rejection is around 99% after 6-month operation. Fig. 11 and Fig. 12 show that 97% and 99% of salt rejection can be sustained after 9-month and 12-month operation.

After conducting the initial level, intermediate level adjustment of the membrane system (includes sand filter, bag filter, UF and RO) operation, the EC of RO permeate is <50 μS/cm and the COD of RO concentrate is <100 mg/L all the time. Besides, the fresh water production of >50% can be maintained all the time as well.

Table 6 shows the water quality of the RO permeate of the pilot plant. The drinking water standard can be satisfied by comparing with the water quality of RO permeate. Table 7 shows the water quality of RO concentrate. The RO concentrate can satisfy the effluent

Table 4
The operation of BioNET pilot plant

Run #	Testing period (2003)	Effluent of WWTP			Effluent of BioNET					
		pH	COD (mg/L)	EC (μS/cm)	pH	COD (mg/L)	COD removal (%)	HRT (hrs)	Volume loading (kg COD/m^3·day)	EC (μS/cm)
1	08.11–09.22	7.53	34	2.393	7.66	25	23	1.20	0.69	2.416
2	09.23–10.08	7.61	56	2.865	7.72	42	22	0.84	1.65	2.839
3	10.09–10.23	7.57	50	2.696	7.62	35	29	0.60	1.99	2.671
4	10.24–11.30	7.45	48	2.963	7.59	36	22	0.48	2.39	2.913

Table 5
The operation of BAC pilot plant

Run #	Testing period (2003)	Effluent of WWTP			Effluent of BAC					
		pH	COD (mg/L)	EC (μS/cm)	pH	COD (mg/L)	COD removal(%)	HRT (hrs)	Volume Loading (kg COD/m^3·day)	EC (μS/cm)
1	08.11–09.18	7.53	34	2.393	7.69	23	29	2.77	0.33	2.417
2	09.19–09.28	7.40	53	3.270	7.57	37	22	1.20	1.06	3.310
3	09.29–11.30	7.57	51	2.718	7.72	41	19	1.71	0.72	2.696

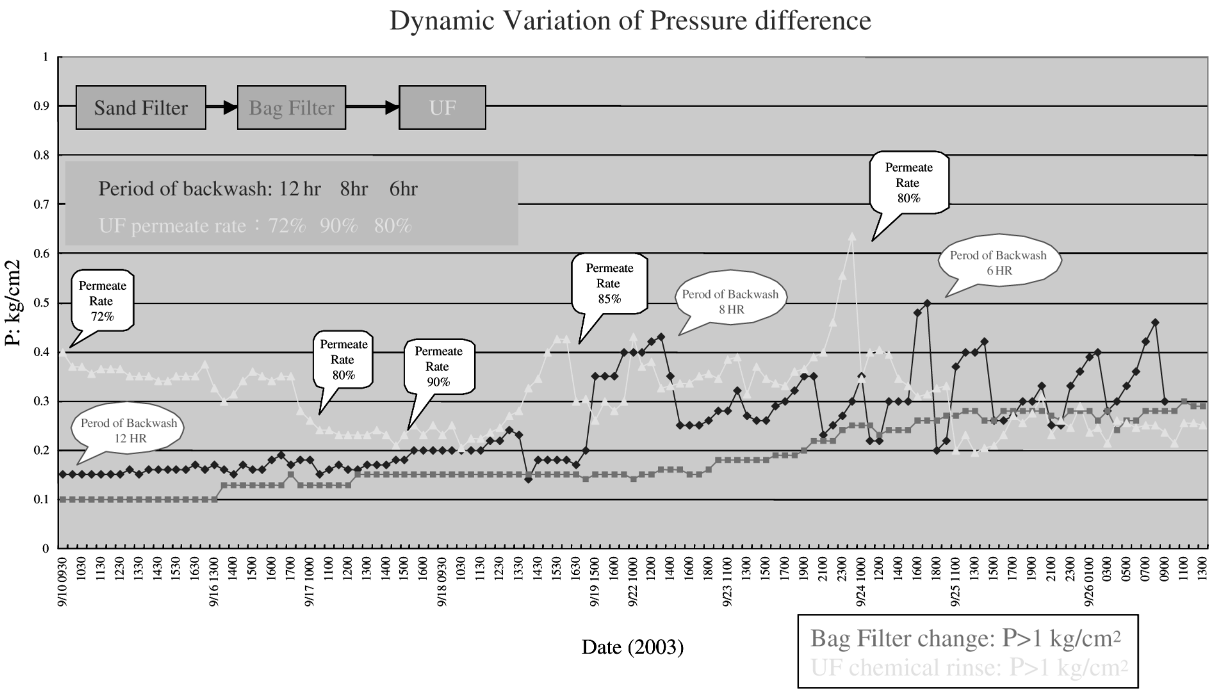

Fig. 9. The pressure differences in the very beginning of pilot operation. —●—Sandfilter; —■—Bagfilter —▲—UFTMP

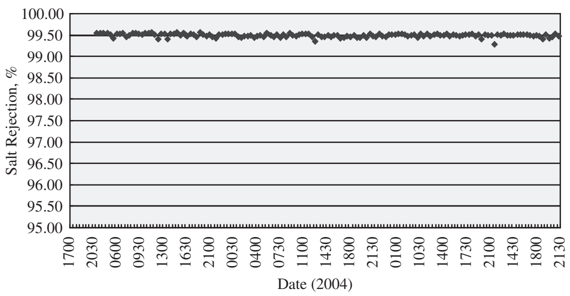

Fig. 10. The salt rejection of RO system after 6-month operation.

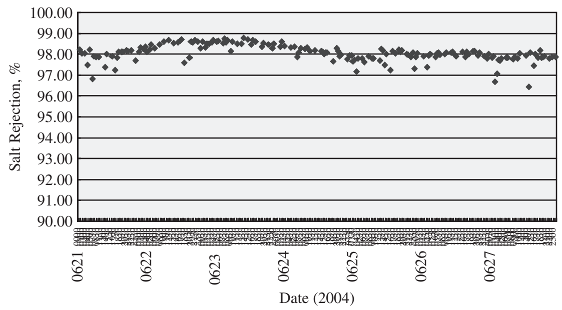

Fig. 11. The salt rejection of RO system after 9-month operation.

standard and be discharged (COD <100 mg/L) according to Table 7.

The following parameters are chosen as the best operational condition after 12-month pilot test

(1) Sand Filter: backwash period 3 hr/cycle (NaOCl 3 ppm), 10 min/wash, sand replacing period 6-month.

(2) Bag Filter: 10 μm-bag recommended, replacing when $\Delta P > 1$ kg/cm^2 or chemical rinse of UF, replacing period around 1 month.

(3) UF: 80% permeate rate, Backwash period 20 min/cycle (NaOCl 10 ppm, NaOH 3 ppm), 30 sec/wash, Chemical rinse once a month (NaOH 3%).

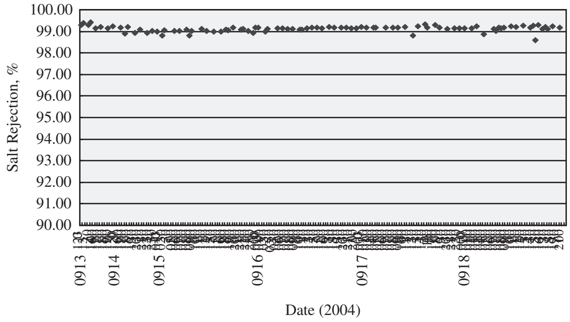

Fig. 12. The salt rejection of RO system after 12-month operation.

(4) RO: 55% permeate rate, Chemical additions (AF-200 3 ppm, $NaHSO_3$ 3 ppm), Chemical rinse (Lemon acid, 30 min each for chemical washing→soaking→chemical washing→rinsing) once every 2 months, >98% rejection rate can be sustained.

The water quality of RO permeate of the pilot plant has been examined and compared with the Drinking Water Standard. Table 6a, b indicates that the water quality of RO permeate is better than the Drinking Water Standard of Taiwan. The brine concentrate of RO reject has been monitored (shown as Table 7) and they can be discharged to the ambient river for qualified quality.

5. The promotion of reclaimed water

Five companies, i.e. Changchuen Resin Inc., Hueifeng Chemistry Inc., Shiuder Technology Inc., Jiengchang Electronics Inc. and Juengching Industry Inc., are chosen to free try the reclaimed water with free shipping and handling (shown as Photo 4 and Photo 5). The applications of the using reclaimed water include: makeup of cooling water, raw water of UPW, and manufacturing water. The positive responses from all of the companies using the reclaimed water have been received. The main responses include: (1). The reclaimed water can help reducing the use of anti-scalant on cooling tower (2). The reclaimed water can reduce EC in the cooling tower effectively (3). The reclaimed water has no effect on UPW production (4). The reclaimed water is suitable for the manufacturing and non-drinking purposes.

Table 8 shows the demand of reclaimed water from the willingness survey after free trial of using reclaimed water in Hsinchu IP. According to Table 8, the total demand of reclaimed water in Hsinchu IP is 7757.5 m^3/d while the demand of the factories is 4827 m^3/d on the east part and 2930.5 m^3/d on the west part. By comparing with the previous survey, the following conclusions can be obtained: (1). The demand of manufacturing water application increases. (2). The demands of cooling water and boiler water application increase in the west part in Hsinchu IP.

6. Planning of wastewater reclamation in WWTP in Hsinchu Industrial Park

Two capacities of wastewater reclamation plant, 5000 m^3/d and 1000 m^3/d of fresh water production, are proposed. The costs (including construction, piping and operational cost) of reclaimed freshwater are NT$20.8 (US$0.62)/ton and NT$17.9 (US$0.54)/ton respectively. Table 9 shows the calculation of the costs of wastewater reclamation in WWTP in Hsinchu IP.

The business plans of BOT, BTO, ROT, OT and BOO are all evaluated for the possible future practice. The BOT and BTO are considered feasible and the fiscal evaluations are followed. The business plan of BTO is preferable according to the payback fiscal study.

Only 3∼16% (much less than the standard of 100%) self-payback rate can be reached for BOT business plan according to Table 10. The 10,000 m^3/d wastewater reclamation plant with BTO business plan is preferable and will have net gain of NT$21,356,000/year (US$640,000/year) according to Table 10.

Table 6a
The water quality of RO permeate and drinking water standard

Item	Turbidity (NTU)	Color (Pt.co)	T (mg/L)	TDS (mg/L)	NH_3N (mg/L)	NO_3N (mg/L)	NO_2N (mg/L)	THM (mg/L)	CN^- (mg/L)	F^- (mg/L)	Cl^- (mg/L)	$SO4^=$ (mg/L)	MBAS (mg/L)	Phenol (mg/L)	As (mg/L)
RO permeate I	0.1	<5	ND	20.2	<0.05	0.28	ND	0.022	ND	0.11	4.2	<5	<0.05	ND	ND
RO permeate II	0.4	<5	ND	42.4	ND	0.35	ND	0.0189	ND	0.13	4.7	2.1	ND	ND	ND
Drinking water standard	2	5	400	600	0.1	10.0	0.1	0.1	0.05	0.8	250	250	0.5	0.001	0.01

Table 6b
The water quality of RO permeate and drinking water standard

Item	Pb (mg/L)	Se (mg/L)	Cr (mg/L)	Cd (mg/L)	Ba (mg/L)	Ti (mg/L)	Ni (mg/L)	Hg (mg/L)	Ag (mg/L)	Fe (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Coli. group (CFU/100mL)	T. Bact count CFU/mL
RO permeate I	ND	ND	0.0006	ND	0.0024	ND	0.0006	ND	ND	0.0066	ND	0.0008	0.0046	2.0E2	1.5E3
RO permeate II	ND	0.001	ND	ND	0.00076	ND	0.00042	ND	ND	0.0057	0.00052	0.0012	0.0070	<1	2.1E3
Drinking water standard	0.05	0.01	0.05	0.005	2	0.01	0.1	0.002	0.05	0.3	0.05	1.0	5.0	6	100

Table 7
The water quality of RO concentrate

Items date (2003)	Effluent of WWTP	Efflunet of BioNET	RO concentrate								
	COD	COD	COD	BOD	SS	Cu	Ni	Fe	Zn	Cr	pH
10/08	39.3	27	113	—	11	0.716	0.635	0.189	0.205	ND	7.38
10/13	29.5	—	88.9	17.6	13	0.777	0.415	0.189	0.17	ND	7.50
10/20	77	41	85	13	8	0.4867	0.5394	0.1677	ND	—	7.6
10/23	65	37	69	10.4	13	0.5330	0.5528	1.8181	0.1156	—	7.0
10/28	94	37	84	17.4	10	0.707	0.512	0.023	0.110	—	7.2
10/30	84	—	218[a]	40.0	23	0.565	0.655	0.185	0.126	—	6.1
11/03	70	39	139[a]	—	18	0.573	0.446	0.194	0.138	—	7.2
11/05	55	41	74	—	13	0.526	0.390	0.161	0.105	—	5.5
11/10	44	—	64	13	6	0.834	0.612	0.059	0.155	—	7.0
11/18	54.9	—	79.4	10	10	0.5	0.1	0.3	0.2	—	6.9
11/20	54.6	35	84.3	12.3	14	0.694	0.571	0.256	0.257	—	7.0
11/24	24.7	—	83.5	—	15	ND	0.15	0.15	0.4	—	7.9
EPA Effluent standard	100	100	100	50	30	3.0	0.5	10	5	2.0	6~9

[a]COD > 100 mg/L, because of low inflow rate and constant amount of anti-scalant added.

Photo 4. The truck loading of reclaimed water.

Photo 5. The unload of reclaimed water at Jieng-chang electronics Inc.

7. Conclusion and suggestion

(1) The project of 10,000 m^3/day WRP is proposed to reclaim 40% of the total effluent of the WWTP of Hsinchu IP. The scope of this research can be applied to the other industrial parks to fulfill the requirement of no-growth industrial water supply.

(2) The long-term (more than 12 months) test on 50 m^3/day WRP pilot plant shows that the effluent of WWTP in Hsinchu IP can be reclaimed to fit the Drinking Water Standard and EC < 50 μS/cm. The concentrate of WRP can also fit the Effluent Standard and can be discharged directly.

Table 8
The demand and application of the reclaimed water

Application	Demand (m^3/d)		Total (m^3/d)	%
	East part	West part		
Cooling tower	1515	1702	3217	41.5
Manufacturing	2110	1024	3134	40.4
Boiler	1040	0	1040	13.4
Firefighting	10	17	27	0.3
Landscape	45	78	123	1.6
Toilet	67	109.5	176.5	2.3
Others	40	0	40	0.5
Total	4827	2930.5	7757.5	100.0

Table 9
The costs of wastewater reclamation in WWTP in Hsinchu IP

Item	5000 m^3/d	10000 m^3/d (1000NT$)
Capital (construction and piping) cost	187,456	316,090
1. Capital cost/year	17,097	28,828
2. Operational cost/year	20,995	36,336
Annual cost	38,091	65,164
Unit cost (NT$/ton)	20.8	17.9

Table 10
The result of payback fiscal study

BOT		
Permeate flow rate	5000 m^3/d	10,000 m^3/d
Self-payback rate	3%	16%
BTO		
Self-payback rate	92%	107%
Interior benefit	2.4%	11.4%
Net gain (NT$1000)	−14,593	21,356

(3) The free trial of using the reclaimed water receives positive responses from all of the companies. The reclaimed water can substantially help reducing EC and the use of anti-scalant in the cooling tower as well as use on UPW production.

(4) The demand of 7757.5 m^3/day reclaimed water is requested. The 10,000 m^3/day WRP is proposed on the first stage of the WRP project with the construction cost of NT$11.3/$m^3$ and operation cost of NT$9.96/$m^3$. The reimbursing BTO business plan is proposed to provide the budget of construction from the government and induce profit for the private participation.

(5) The cost of reclaimed water will be lower than NT$10/$m^3$ when the reimbursing BTO business plan is applied. The tariff of reclaimed water is proposed equal or lower than the water supply tariff in order to raise the public acceptance.

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