MAXIMUM WATER RECOVERY FOR A SERIES OF WATER TREATMENT UNITS IN A SEMICONDUCTOR PLANT

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ABSTRAK

Penggunaan air semakin bertambah setiap tahun berpunca daripada permintaan yang tinggi untuk kegunaan pelbagai di dalam bidang industri. Bagi mengurangkan jumlah permintaan air bersih, maka sesebuah industri perlulah mempunyai sistem pengurusan air yang cekap. Kaedah analisis jepit air adalah satu kaedah sistematik untuk merekacipta rangkaian air kitar semula bagi meminimakan penggunaan air bersih dan memaksimakan penggunaan semula air sisa melalui integrasi aktiviti dan proses. Kertas kerja ini mengkaji keberkesanan memasukkan air sisa guna semula ke dalam lokasi berlainan di dalam sebuah unit pembersihan air yang disusun secara bersiri dengan menggunakan kaedah analisi jepit air. Kaedah ini telah diaplikasikan pada sebuah kajian kes semikonduktor. Hasil kajian menunjukkan bahawa kemasukan air guna semula ke dalam lokasi berlainan di dalam sebuah unit pembersihan air yang disusun secara bersiri dapat meningkatkan lagi jumlah penjimatan air bersih. Ia juga menurunkan kos operasi unit perbersih air tersebut.

Kata Kunci: Analisis Jepit Air, unit pembersih, air minima, guna air maksima, jadual kumulatif

ABSTRACT

Nowadays, water demands are growing every year because most process industries and buildings use water for a wide range of applications. In order to reduce water demand, industries have come out with a better water management and water minimisation technique. Water pinch analysis (WPA) is a systematic technique for the design of water recovery network to minimize the water demands and maximize water reuse and recycling through integration of water using activities and process. This paper considers maximizing water recovery considering injecting reused wastewater to different location of a series water treatment units using water pinch analysis. The method was employed to a semiconductor plant case study. The result shows that consideration of bypassing some water treatment system unit increases further freshwater savings. It also decreases operating cost of the treatment units.

Keywords: Water Pinch Analysis, treatment unit, water minimization, maximum water recovery, cascade table

1.0 INTRODUCTION

Water demand is increasing every year as a result of the growing world population. It is estimated that more than 2.8 billion people in 48 countries will lack access to adequate water supplies by 2025 [1]. The looming water crisis and sharp increase in water tariff has particularly encouraged the industrial sector to improve efficiency in managing fresh water usage and wastewater generation.

The purpose of this paper is to perform maximum water recovery considering various injection points locations for a series of water treatment units based on Water Pinch Analysis (WPA) for a semiconductor plant water system. Though WPA has matured since its introduction by Wang and Smith [2], most authors only considers on maximizing reuse and wastewater regeneration. Wan Alwi and Manan [3] has introduces the concept of minimum water network which includes maximizing water elimination, reduction, reuse/outsourcing and wastewater regeneration. Wastewater regeneration refers to treatment of wastewater to match the quality of water required for further use. Work on wastewater regeneration has included work on minimization of wastewater regeneration units considering various configurations [4-9].

However, as has been neglected by previous authors, there are certain cases where regeneration does not involve treating wastewater but instead making clean water from the water provider purer. This is the case for processes that needs ultrapure or deionised water such as in a semiconductor plant. In this case, it is not correct to term the system as regeneration as it does not involve purifying the water again to something it was originally. Hence, we termed the process as water treatment. In this work, maximizing water reuse for a series of water treatment units is considered instead of wastewater regeneration units.

Typically, a set of wastewater regeneration unit that produces purer water source is more expensive, hence water injection to treatment unit that produces the lowest water source purity (upstream) is maximized first followed by increasing water purity treatment units (**Figure 1a**). The reverse applies to maximize freshwater savings for a series of water treatment unit. Here, water reuse must be considered to be used at the water treatment unit that needs the purest inlet (downstream) first (**Figure 1b**). This approach can lead to lower operating cost and also reduced wastewater from the earlier water treatment units.

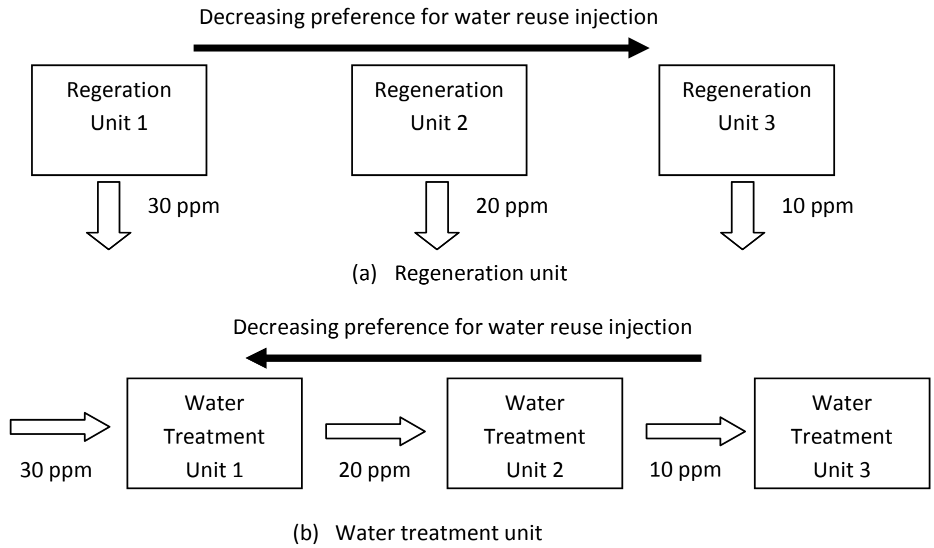

Figure 1. Water reuse injection for (a) regeneration, and (b) water treatment units in series.

Wan Alwi and Manan [3] has proposed a maximum water recovery system for a semiconductor plant. However, the water reuse was only injected into the blend water tank that goes into multimedia filtration, the beginning of the deionised (DI) water treatment process unit (see **Figure 2**). This paper analyses the various water treatment locations and proposes the best location to inject water reuse. For the semiconductor case study, the multimedia filter, first pass reverse osmosis and EDI water treatment unit inlet are considered. Treatment units after electro-deioniosation (EDI) unit is not considered since the water here is already near to ultrapure. By injecting water reuse at other locations of the DI water treatment units, more freshwater consumption can be saved and wastewater can be reduced from the treatment unit (e.g. reject water, backwash, rinse water). This also leads to reduction in treatment unit load, indirectly reducing the operating cost of the treatment units. Note that EDI unit uses a lot of electricity to deionise the water which contribute to the operating cost.

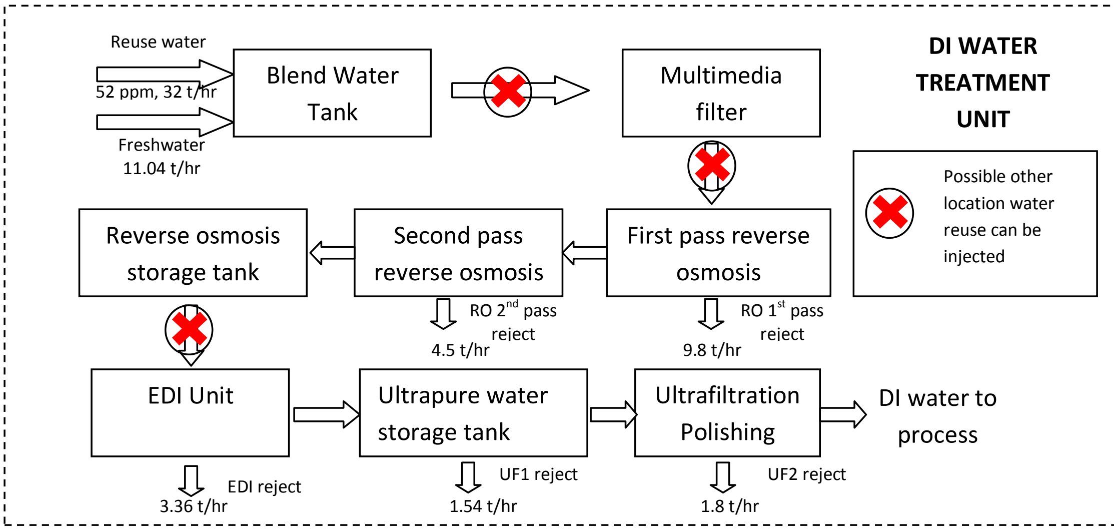

Figure 2. Deionised (DI) production water treatment unit.

There is a correlation between amount of water going into each of the treatment unit and also amount of wastewater rejected from treatment unit. Furthermore, the wastewater rejects from the treatment unit also correspond as potential water sources to be reused. Hence, the system becomes not so straight forward as shown in **Figure 3**. All this will be taken into consideration in this paper.

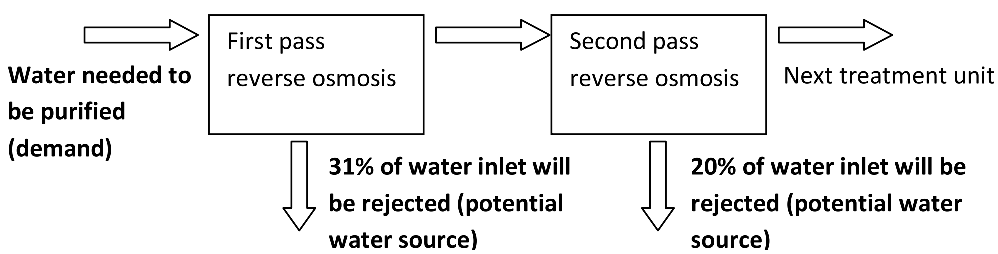

Figure 3. Correlation between water going into the unit and its wastewater.

2.0 METHODOLOGY

The first step is to extract the limiting water data, which include water flowrate and the maximum contaminant concentration for water sources (outlet) and demand (inlet) for the series of water treatment units. The next step is to extract the equations which relate the water treatment unit inlet flowrate to the amount of rejected wastewater. The targets for maximum water recovery and minimum wastewater generation are then set using the Water Cascade Analysis (WCA) technique developed by Manan *et al.* [10] starting by optimizing the water treatment unit with highest purity water inlet demand to the lowest purity water inlet demand. The final step is to perform economic analysis to estimate the total savings from the new configuration.

3.0 RESULTS AND DISCUSSION

3.1 Data Extraction

Table 1 shows the limiting water data for the semiconductor plant from Wan Alwi and Manan [3] before any process changes. Note that multimedia filter (MMF) inlet refers to amount of water needed from blend water tank. This is also the place where reuse wastewater is feed. The initial freshwater consumption and wastewater generation of the semiconductor plant before water integration are 47.78 t/hr and 36.76 t/hr respectively. Initially, blend water tank is satisfied by using 32 t/hr of freshwater at 30 ppm.

Table 1. Initial limiting water data for semiconductor plant considering MMF inlet as demand.

	Demand	F, t/hr	C, ppm		Source	F, t/hr	C, ppm
D1	MMF inlet	32.0	52	S1	MMF rinse	1.33	48.0
D2	Cooling tower	6.00	100	S2	RO reject 1st pass	9.80	70.4
D3	Abatement	2.73	100	S3	EDI reject	3.36	48.6
D4	Scrubber	0.54	100	S4	WB101 rinse water, idle	0.38	0
D5	Toilet flushing	0.08	100	S5	WB101 rinse water, operation	0.07	4608
D6	Wash basin	0.01	52	S6	WB102 rinse water, idle	0.22	0
D7	Ablution	0.15	52	S7	WB102 rinse water, operation	0.07	4480
D8	Toilet pipes	0.12	52	S8	WB201 rinse water, idle	0.76	0
D9	Office cleaning	0.05	52	S9	WB201 rinse water, operation	0.03	23360
D10	MMF backwash	2.08	52	S10	WB202 rinse water, idle	3.48	0
D11	MMF rinse	1.33	52	S11	WB202 rinse water, operation	0.07	163.2
D12	WB203 cooling	1.47	52	S12	WB203 rinse water, idle	3.63	0
D13	WB202 cooling	1.22	52	S13	WB203 rinse water, operation	0.28	928
Total water demands		**47.78**	**t/hr**	S14	MAU	1.11	6.4
				S15	AHU	0.36	11.5
				S16	Cassette cleaner	0.08	0
				S17	Abatement	2.73	105.6
				S18	Wafer scrubber	0.54	12.8
				S19	RO reject 2nd pass	4.50	19.2
				S20	UF1 reject	1.54	19.2
				S21	UF2 reject	1.80	0
				S22	Heater WB101	0.46	0
				S23	Wash basin	0.01	60
				S24	Ablution	0.15	40
				Total water sources		**36.76**	**t/hr**

In order to take into account the multiple treatment units, the following data are assumed:

1. Total dissolved solids (TDS) contaminant concentration for each treatment unit:
   - MMF inlet = 52 ppm
   - 1st pass RO inlet = 45 ppm
   - 2nd pas RO inlet = 8 ppm
   - EDI inlet = 1.85 ppm

2. Wastewater rejects flowrate for each treatment unit:
   - Multimedia filter (MMF) backwash ($X_{MMF,B}$) = 6% of water into MMF unit
   - Multimedia filter (MMF) rinse ($X_{MMF,R}$) = 4% of water into MMF unit
   - First pass RO reject ($X_{RO,1}$) = 31% of water into 1st pass RO unit
   - Second pass RO reject ($X_{RO,2}$) = 20% of water into 2nd pass RO unit

3. Total water needed to enter EDI unit from RO tank = 17.69 t/hr (not including EDI return)
4. Total water needed to enter EDI = 45.36 t/hr

3.2 Single treatment unit inlet targeting

Table 2 shows the Water Cascade Table (WCT) by Wan Alwi and Manan [3] for the maximum water recovery considering water reuse is only fed into blend water tank. The blend water tank needs 32 t/hr of freshwater and water reuse mixed at 52 ppm. The freshwater and wastewater flowrate targets are 11.04 t/hr and 0.02 t/hr respectively. Note from **Table 2** that the cleanest water targeted water at 0 ppm concentration actually referred to DI water (F_{DI}) needed to be supplied to the blend water tank instead of freshwater. This was because freshwater for the semiconductor plant had a concentration of 30 ppm. The source water flowrate at 30 ppm shown in **Table 2** was actually the amount of freshwater supply needed.

Table 2. Water cascade table for maximum water recovery considering water reuse only goes into the first water treatment unit.

Conc, C (ppm)	Purity, P	ΔP	Sum F demand, t/hr	Sum F source, t/hr	Total F, t/hr	Cum water flowrate, t/hr	Water surplus, t/hr	Cum water surplus, t/hr	$F_{FW, cum}$, t/hr
						$F_{DI} = 0$			
0	1			10.808	10.808				
		6.4E-06				10.808	6.92E-05		
6.4	0.999994			1.11	1.11			6.92E-05	10.80800
		5.12E-06				11.918	6.1E-05		
11.52	0.999988			0.36	0.36			0.00013	11.30133
		1.28E-06				12.278	1.57E-05		
12.8	0.999987			0.54	0.54			0.000146	11.39900
		6.4E-06				12.818	8.2E-05		
19.2	0.999981			6.04	6.04			0.000228	11.87200
		1.08E-05				18.858	0.000204		
30	0.99997			**F_{FW} = 11.04**	11.04			0.000432	14.38696
		1E-05				29.898	0.000299		
40	0.99996			0.15	0.15			0.000731	18.26472
		8E-06				30.048	0.00024		
48	0.999952			1.33	1.33			0.000971	20.22860
		6.4E-07				31.378	2.01E-05		
48.64	0.999951			3.36	3.36			0.000991	20.37530
		3.36E-06				34.738	0.000117		
52	0.999948		-38.43	0	-38.43			0.001108	21.30335
		8E-06				-3.692	-3E-05		
60	0.99994			0.01	0.01			0.001078	17.97064
		1.04E-05				-3.682	-3.8E-05		
70.4	0.99993			9.8	9.8			0.00104	14.77196
		2.96E-05				6.118	0.000181		
100	0.9999		-9.35		-9.35			0.001221	12.21039
		5.6E-06				-3.232	-1.8E-05		
105.6	0.999894			2.73	2.73			0.001203	11.39147
		5.84E-05				-0.502	-2.9E-05		
164	0.999836			0.069	0.069			0.001174	7.15624
		0.000764				-0.433	-0.00033		
928	0.999072			0.278	0.278			0.000843	0.90820
		0.003552				-0.155	-0.00055		
4480	0.99552			0.069	0.069			0.000292	0.06524
		0.000128				-0.086	-1.1E-05		
4608	0.995392			0.071	0.071			0.000281	0.06104
		0.018752				-0.015	-0.00028		
23360	0.97664			0.034	0.034			0	**0 (Pinch)**
		0.97664				**F_{WW} = 0.019**	0.018558		

3.3 Multiple treatment unit inlet in series targeting

For multiple treatment unit inlets in series targeting, **Table 3** shows the limiting water data assuming EDI and first pass reverse osmosis (RO) inlet can accept water with certain contaminant limit. **Table 4** shows the WCT obtained. The new freshwater and wastewater target are 9.05 t/hr and 0.03 t/hr respectively. 12.31 t/hr of water reused are injected into EDI inlet directly and 9.75t/hr into first pass RO inlet. No water reused or freshwater needed to be injected into multimedia filtration hence reducing the capital cost. Direct injection into EDI unit also reduces the RO system capacity and water rejects. **Figure 4** shows a simplified water network design for the DI water treatment unit.

Table 3. Limiting water data considering multiple treatment units as demand.

j	Demand	F, t/hr	C, ppm
D1	MMF inlet	0	52
D2	Cooling tower	6	100
D3	Abatement	2.73	100
D4	Scrubber	0.54	100
D5	Toilet Flushing	0.08	100
D6	Wash basin	0.01	52
D7	Wudhuk	0.15	52
D8	Toilet pipes	0.12	52
D9	Office cleaning	0.05	52
D10	MMF backwash	0	52
D11	MMF rinse	0	52
D12	WB203 cooling	1.47	52
D13	WB202 cooling	1.22	52
D14	EDI inlet	12.31	1.85
D15	1st pass RO inlet	9.75	45

i	Source	F, t/hr	C, ppm
S1	Wash basin	0.01	60
S2	MMF rinse	0	48
S3	RO reject 1st pass	3.02	70.4
S4	EDI reject	3.36	48.64
S5	WB101 idle	0.38	0
S6	WB102 idle	0.22	0
S7	WB201 idle	0.76	0
S8	WB202 idle	3.49	0
S9	WB203 idle	3.63	0
S10	MAU	1.11	6.4
S11	AHU	0.36	11.52
S12	Cassette cleaner	0.08	0
S13	Abatement	2.73	105.6
S14	Wafer scrubber	0.54	12.8
S15	RO reject 2nd pass	1.35	19.2
S16	UF1 reject	1.54	19.2
S17	UF2 reject	1.8	0
S18	Freshwater	7.73	30
S19	WB101 operation	0.07	4608
S20	WB102 operation	0.07	4480
S21	WB201 operation	0.07	23360
S22	WB202 operation	0.03	164
S23	WB203 operation	0.28	928
S24	Wudhuk	0.15	40
S25	Heater WB101	0.46	0

Table 4. Water cascade table for multiple water treatment units in series.

Conc, C (ppm)	Purity, P	ΔP	Sum F demand, t/hr	Sum F source, t/hr	Total F, t/hr	Cum water flowrate, t/hr	Water surplus, t/hr	Cum water surplus, t/hr	$F_{FW, cum}$, t/hr
						F_{DI} = 0			
0	1.0000			10.8080	10.8080				
		0.0000				10.8080	0.0000		
1.85	1.0000		**F_{EDI} = -12.3084**		-12.3084			0.0000	10.8080
		0.0000				-1.5004	0.0000		
6.4	1.0000			1.1100	1.1100			0.0000	2.3524
		0.0000				-0.3904	0.0000		
11.52	1.0000			0.3600	0.3600			0.0000	1.1111
		0.0000				-0.0304	0.0000		
12.8	1.0000			0.5400	0.5400			0.0000	1.0233
		0.0000				0.5096	0.0000		
19.2	1.0000			2.8854	2.8854			0.0000	0.8611
		0.0000				3.3950	0.0000		
30	1.0000			**F_{FW} = 9.0450**	9.0450			0.0001	1.7902
		0.0000				12.4400	0.0001		
40	1.0000			0.1500	0.1500			0.0002	4.4527
		0.0000				12.5900	0.0001		
45	1.0000		**F_{RO1} = -9.74935**		-9.7493			0.0002	5.3568
		0.0000				2.8407	0.0000		
48	1.0000			0.0000	0.0000			0.0002	5.1996
		0.0000				2.8407	0.0000		
48.64	1.0000			3.3600	3.3600			0.0003	5.1514
		0.0000				6.2007	0.0000		
52	0.9999		-3.02		-3.0200			0.0003	5.2120
		0.0000				3.1807	0.0000		
60	0.9999			0.0100	0.0100			0.0003	4.9411
		0.0000				3.1907	0.0000		
70.4	0.9999			3.0223	3.0223			0.0003	4.6911
		0.0000				6.2130	0.0002		
100	0.9999		-9.35		-9.3500			0.0005	5.1476
		0.0000				-3.1370	0.0000		
105.6	0.9999			2.7300	2.7300			0.0005	4.6787
		0.0001				-0.4070	0.0000		
164	0.9998			0.0690	0.0690			0.0005	2.8801
		0.0008				-0.3380	-0.0003		
928	0.9991			0.2780	0.2780			0.0002	0.2307
		0.0036				-0.0600	-0.0002		
4480	0.9955			0.0690	0.0690			0.0000	**0 (Pinch)**
		0.0001				0.0090	0.0000		
4608	0.9954			0.0710	0.0710			0.0000	0.0005
		0.0188				0.0800	0.0015		
23360	0.9766			0.0340	0.0340			0.0015	0.0643
		0.9766				**F_{WW} = 0.1140**	0.1113		
								0.1128	0.1128

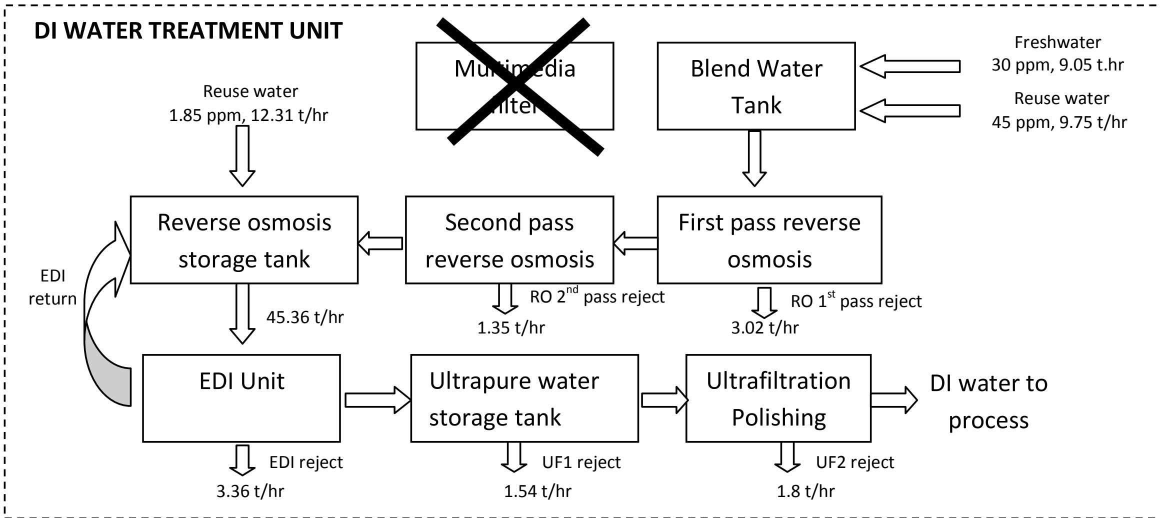

Figure 4. Final network design for water treatment unit in series.

3.4 Economic Analysis

Table 5 shows the operating cost formulas assumed. **Table 6** shows the economics between injecting in the first and various locations of a series of water treatment units. It can be seen that by considering injecting at a later stage of a water treatment unit, a savings up to $ 198, 749 per year can be achieved. This is 20.8% higher than considering injecting only in the first treatment unit.

Table 5. Operating cost formulas.

Process	Type of OC	Cost formula	Unit
JBA cost, C_{FW}	Freshwater	$0.518F_{FW\,new}$	$/t
Industrial wastewater cost, C_{IWT}	Wastewater	$0.042F_{WW\,new}$	$/t
MMF operating cost, C_{MMF}	Chemical	$0.061F_{MMF\,new}$	$/t
RO operating cost, C_{RO}	Chemical	$0.058F_{RO,1\,new}$	$/t
EDI operating cost, C_{EDI}	Chemical and electrical	$0.017F_{EDI\,new}$	$/t

Table 6. Economics between using single and multiple water treatment units.

	Before Minimum Water Network (MWN)	MWN with inject in Single Treatment Unit	MWN with inject in Multiple Treatment Units
Freshwater Flowrate, t/hr	47.78	11.04	9.05
Wastewater Flowrate, t/hr	36.76	0.019	0.11
Freshwater reduction, %		76.90	81.10
Water reduction, %		99.90	99.70
Freshwater savings, $/year		152,25	160,518
Wastewater treatment cost savings, $/yr		12,35	12,313
MMF Filter inlet, t/hr	32	32.00	0
First pass RO inlet, t/hr	31.99	31.99	9.75
EDI Inlet, t/hr	45.36	45.36	45.36
MMF Cost, $/yr	15594	15594	0
RO Cost, $/yr	14850	14850	4526
EDI Cost, $/yr	6239	6239	6239
Total savings, $/yr		164,60	198,749

4.0 CONCLUSION

As a conclusion, water reuse injected should be maximized at the downstream of water treatment units and going upwards. A case study on semiconductor plant has yielded an increase of cost savings of 20.8%.

NOMENCLATURE

C	-	Contaminant concentration, ppm
CFW	-	Costs per unit time for freshwater
CWW	-	Costs per unit tile for wastewater disposal
FDI	-	Desionised water flowrate
FEDI new	-	New electrodeionisation flowrate after analysis
FFW	-	Freshwater flowrate
FFW new	-	New freshwater flowrate after analysis
FMMF new	-	New multimedia filter inlet flowrate after analysis
m	-	Mass load
n	-	number of purity intervals
P	-	Purity
ppm	-	Parts per million
S	-	Source
t/h	-	Tonne per hour
i	-	sources
j	-	Demands/sinks

DI	-	Deionised water
EDI	-	Electrodeionisation
FW	-	Freshwater
MMF	-	Multimedia filter
MWN	-	Minimum Water Network
RO	-	Reverse osmosis
UF	-	Ultra filtration
UV	-	Ultraviolet
WW	-	Wastewater

ACKNOWLEDGEMENTS

The authors would like to thank Malaysia Ministry of Science, Technology and Innovation (MOSTI) and Universiti Teknologi Malaysia for the financial support.

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