Water Pinch Analysis: Recycling Waste Water for Minimization of Fresh Water Consumption

By

Hamzah Bin Nawawi

A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

DECEMBER 2011

Universiti Teknologi PETRONAS,
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CERTIFICATION OF APPROVAL

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Approved by,

____

[Dr Mohamed Ibrahim Abdul Mutalib (Assoc. Prof)]

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

HAMZAH BIN NAWAWI

ABSTRACT

Water is one of the important elements in a process plant. It is the most effective thing to be used as the coolen in plant. As we know, from total water usage in the world, 20% of the amount is used in the industry field. Only 2.5% water in the world is considered as fresh water while the rest is salt water. Almost 80% of diseases in so called developing countries are associated with water, causing some three million early deaths. The world's industry currently is enforced to concern regarding the sustainability issue. They need to ensure that all the aspects that is related to the environment's issue is being concerned first before considering other factors. It would give the impact on the cost of the fresh water if it is not being controlled.

Recently, many studies regarding the system to recycle and reuse waste water had been conducted. Those ideas come in line with the current situation that occur all over the world which is water crisis. In Malaysia, eventhough we are receiving a big amount of rain water every year, we need to aware that the world is changing and sometimes it is out of our expectation. Prevention is better than cure. Synchronize with that, there are several group that are currently did the research for this and come up with a system to be implemented. For example, in Universiti Teknologi Malaysia, a system to recycle and reuse the waste water from the mosque is being implemented. It shows that by doing so, we could save lots of water by using it effectively

.To perform this study, main research element to be use is Water Cascade Analysis (WCA) and following its steps. It is a new method to determine the minimum water and wastewater targets for water using processes. Therefore, this system will be use for this project will be a combination of research element from previous case problems and also to create new design in recycling and reusing the waste water to be used as the source of cooling tower water. The study would be based on the waste water specification from Final Check Basin (T-610) in waste water plant in one of the petrochemical waste water treatment plant in Malaysia.

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All praises to Allah the Almighty who help me and gave me strength, inspiration and patience to finish this research. It is only with His help, blessings and guidance and only by His will that I finally managed to complete this project.

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CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background of Study

Water is used as the raw material to be fed into a reactor or as a cooling or heating medium. It is clearly a typical of non-mass transfer operations because they are not designed to favourably transfer contaminant between streams. For non-mass transfer based water using operations, water flow rate is more important than the amount of contaminant accumulated. Thus, this type of process can have different inlet and outlet flow rates. Conventional water network studies are focused on mass-transfer based process. But, recent studies have shown that the non-mass transfer based water-using operations are also need to be considered.

Basically, in this project we will use the water cascade analysis (WCA) to establish the minimum water targets, that is, the overall fresh water requirement and wastewater generation for a process after looking at the possibility of using the available water sources within a process to meet its water demands. WCA is done in order to establish the minimum water and wastewater targets in a maximum water recovery (MWR) network. The WCA eliminates any tedious iterative step to quickly yield the exact utility targets and the pinch locations.

After obtaining all the data, a design will be modeled on water reuse, waste water minimization and effluent-treatment system design so it could be reuse as the feed water in order to minimize the fresh water consumption and waste water production. This study will be based on the data obtained from waste water treatment plant in one of the petrochemical plant in Malaysia.

1.2 Problem Statements

The environmental impact of industrial wastewater and much higher cost of raw water are serious challenges facing the chemical process industries nowadays. Currently, the waste water treatment is just treating the waste effluent from the processes unit area to be discharged to sea. Instead of just being dumped to the sea, it is good if we could redesign the water network system there to be recycled. It could help the company to conserve the water consumption and also the cost for buying the raw water. It would also help the company to practise the sustainability technology that would help them in establishing the image and credibility of the company.

1.3 Aims and Objectives

1. To study the current process flow sheet data of the water network system and extract the data in locating the water sources and water demands.
2. To determine the minimum water targets and waste water targets.
3. To redesign the water network system especially in water treatment process to incorporate with the minimization of fresh water utilization.

1.4 Scope of Study

In order to complete this system, several scope of study had to achieve. The major scopes are as follows:

1. To establish the minimum water and wastewater targets in a maximum water recovery (MWR) network.
   - Extracting the data from the process flow sheet of the water networking system to get all the water sources and water demands.
   - Using the water cascade analysis to completely establish this demand.
   - Looking at the possibility of using the available water sources within a process to meet its water demands.

2. Designing a model of waste water reuse to be implemented.

- Water reuses is evaluated based on typical water-reuse opportunities based on past experience.
- Comparing the new network design with the original design.

CHAPTER 2

LITERATURE REVIEW

2.1 EXPANSION OF TECHNOLOGY

The first attempt to solve water recovery network was done by Takama for petroleum refinery problem. He was trying to utilise a mathematical programming approach to set up a superstructure of all water-using operations. It is then optimised to remove the irrelevant and uneconomical options.

After that, Wang and Smith initiated the water pinch technique based on the generalised problem of mass exchange network synthesis (MENS). In MENS's procedure, the limiting composite profile is introduced to locate the minimum fresh water and waste water flow rates prior to any water network design. They were also exploring the regeneration-reuse and the regeneration-recycle opportunities based on the basic concept underlying this concept which is the water using processes are modelled as mass transfer operations.

The problem occurred was that the mass transfer model-based approach in handling the water recovery network might not always be sufficient. It was failed to be applied on some operations of the industry where water quantity is more important than water quality. For example, it was not applicable to be implemented for the operations such as boiler blow down, cooling tower make-up and reactor effluent treatment.

Later, Dhole corrected the targeting approach by introducing a new water source and demand composite curve. They were also showed that proper mixing or by passing could further reduce the fresh water consumption.

More recently, Hallale discovered that the water source and water demand composite curves may not give clear picture of the analysis. The targets obtained may not be a true solution as they are greatly depending on the mixing patterns of the process streams. In turn, a water surplus diagram is presented for the targeting of minimum fresh water consumption and waste water generation in a water recovery network. However, the usage of water surplus diagram involves tedious

After the water cascade analysis had been done, we will get the establishment of minimum water and waste water targets in a maximum water recovery (MWR). The next step is to design the water network system so that we could recycle the waste water for the cooling tower utilization. This is done in order to reduce the usage of water consumption. Two possible scopes for process changes to further reduce the water targets and thus water consumption are including the water regeneration and equipment or hardware modifications.

For designing the model, especially in reusing or recycling the wastewater, it will involve the use of pollutant-laden streams within the process. Basically, the key elements for this is separation technology. It is important in ensuring this system to recover valuable materials such as solvents, metals, inorganic species and water.

If this technology could be implemented it in plant, it is belived that the management could effectively used the source of water and optimizing the cost for fresh consumption. Furthermore, it could improve the image of the company as they show their effort to fulfill the social obligation towards sustainability of the environment.

WATER CASCADE ANALYSIS

The first step in doing this analysis is to extract the data from the water network flow sheet. We should find out the number of water sources and also water demands. We need to get these streams data as it will be the main element in forming up the limiting water data for this project. The tables are being made by using Microsoft Excel.

Water Demand, D_j	Flow rate, F_j (ton/h)	Concentration, C_j (ppm)	Water Sources, D_i	Flow rate, F_i (ton/h)	Concentration, C_i (ppm)
1			1		
2			2		
.			.		
.			.		
.			.		
n			n		

Table 1: General Table of Limiting Water Data

Next, we need to list up all contaminant concentration [C] of the water processes. If there is any duplicate of concentration, we should remove it from the table. It will be arranged in ascending order, similar in setting up the global temperature intervals in problem table analysis for heat exchange network synthesis (HENS).

C	P	ΔP	ΣF_{WDi}	ΣF_{WSj}	$\Sigma F_{WDi} + \Sigma F_{WSj}$	ΣF	ΔP x ΣF	Cumulative (ΔP x ΣF)
						F_{FW}		
1	1				$\Sigma F_{WD1} + \Sigma F_{WS1}$			
2	2				$\Sigma F_{WD2} + \Sigma F_{WS2}$			
.	.				.			
.	.				.			
.	.				.			
n	n				$(\Sigma F_{WDi} + \Sigma F_{WSj})_n$			
						F_{WW}		

Table 2: General structure of water cascade table

After we have listed up all the contaminant concentration, we need to calculate the purity of each concentration column. The first purity is named as P_1, then P_2 until P_n. As the concentration of pure water is one million ppm, the water purity of contaminated stream is defined as :

$$P = \frac{1000000 - C}{1000000}$$

After we get all the purity values, we should calculate the purity difference [ΔP].

$$\Delta P = P_n - P_{n+1}$$

Flow rate of all the water demands (F_{WD}) and sources (F_{WS}) are summed at each purity level in column of $\sum F_{WD_i}$ and $\sum F_{WS_j}$ respectively. Note that the water demands are written as negative values while the water sources are positive. We then add up the water demands and sources in the sixth column ($\sum F_{WD_i}$ + $\sum F_{WS_j}$). A positive value in this column is designating a net surplus of water presents at its respective level and the negative value is showing that a net deficit of water.

The column of cumulative flowrate ($\sum F_W$) is showing us how the cascade is happened. The first row in this column is estimated the flow rate of fresh water required for water using processes [$\sum F_{FW}$]. The next row will be added (starting from second row till end) to get the cumulative water flow at its purity level. The total cumulative water flow rate values in the final are representing the total waste water that is generated.

In the next column, the multiplication values between the purity difference and cumulative flow rate (ΔP x ΣF) are calculated at every purity level. These values show the pure water surplus or deficit in each region. Lastly, cumulative of (ΣF x ΔP) is obtained. It represented the situation in the water surplus diagram. With the assumed fresh water flow rate, if negative value exists, this means that there will not be sufficient water purity in the networks. Thus, more fresh water needs to be added until no value of the column is negative. The minimum fresh water target will be the flowrate that causes zero to appear at this cumulative column. The zero that appears is the pinch point.

SYSTEMATIC CLASSIFICATION OF SCENARIOS IN WATER-USING PROCESSES

Many scenarios may take place when the water-using processes are analysed. Systematic classification of the scenarios will help us in managing the problem easily. Normally, four different situations may occur when water-using processes are analysed in a global manner:

1. Processes where only water demands occur **($\sum FWS = 0$)**
2. Processes where only water sources occur **($\sum FWD = 0$)**
3. Processes with total flowrate of water demands is higher than or equal to the total flowrate of water sources **($\sum FWDi \geq \sum FWSj$)**
4. Processes where total flowrate of water demands is lower than the total flowrate of water sources **($\sum FWDi < \sum FWSj$)**

Targeting procedure for each of the above situation is different. In the first condition, where in the process only water demands occur, the fresh water that is required is equal to the total flowrate of all the water demands **($FFW = \sum FWD\,j$)**. The pinch purity will be discovered at the demands with lowest purity level. In this situation, there will be no wastewater generated from the processes. Figure 1 shows the water surplus diagram of this situation, where all the water demands are located at the negative side of the x-axis.

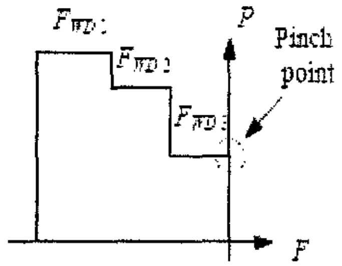


Figure 2: Water surplus diagram with water demands only

When there is only water sources occurred, no fresh water is required in these processes. Wastewater that is generated from these processes is same as the total flowrate of all the water sources (**$F_{WW} = \sum F_{WS\,j}$**). Highest purity of water source will be incur as the pinch purity for the process.

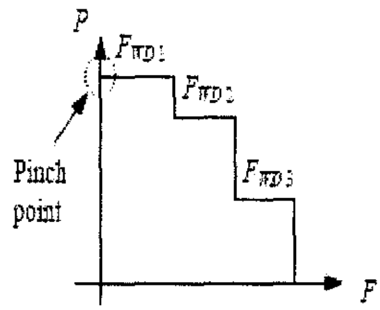


Figure 3: Water surplus diagram with water sources only

In the third situation where the total flowrate of water demands of the water-using process is more than the total flowrate of water sources ($\sum F_{WDi} \geq \sum F_{WSj}$), fresh water flowrate ($F_{FW,est}$) need to be estimated, where,

$$F_{FW,\,est} = \left| \sum F_{WD\,i} + \sum F_{WS\,j} \right| \quad (3)$$

To see whether any negative value occurs, the column of cumulative ($\sum F$ x $\sum P$) is then checked. Minimum fresh water needed is equal to the estimated fresh water flowrate ($F_{FW} = F_{FW,\,est}$) if all the values are positive. The pinch purity discover at the demand with the lowest purity level. If any negative value is observed, more fresh water is needed. To guess an estimated fresh water flowrate a simple trial-or-error solution is needed to be done until all negative values in the column are removed. The minimum fresh water target will be the flowrate that causes zero (pinch point) to occur at the cumulative column.

In the final scenario,when the total flowrate of water demands is less than the total flowrate of all the water sources (**$\Sigma FWD\ i < \Sigma FWS\ j$**), water demands and sources purity is taken into contemplation. No fresh water is needed if the purity of water sources is higher than or equal to that of the water demands (**$PWS \geq PWD$**). Wastewater generated is estimated to be [16]:

$$FWW = \Sigma FWS\ j + \Sigma FWD\ i \quad (4)$$

On the other hand, if the purity of water sources is lower than that of the water demands, fresh water are needed for the processes. Procedure of targeting the fresh water flowrate is the same as were in the third scenario, where an estimated fresh water flowrate (*FFW est*) is needed (Eq. 3) to reach a pinch purity to occur at the cumulative column of the WCT. Figure 3 shows the summary of the overall targeting procedure by WCT.

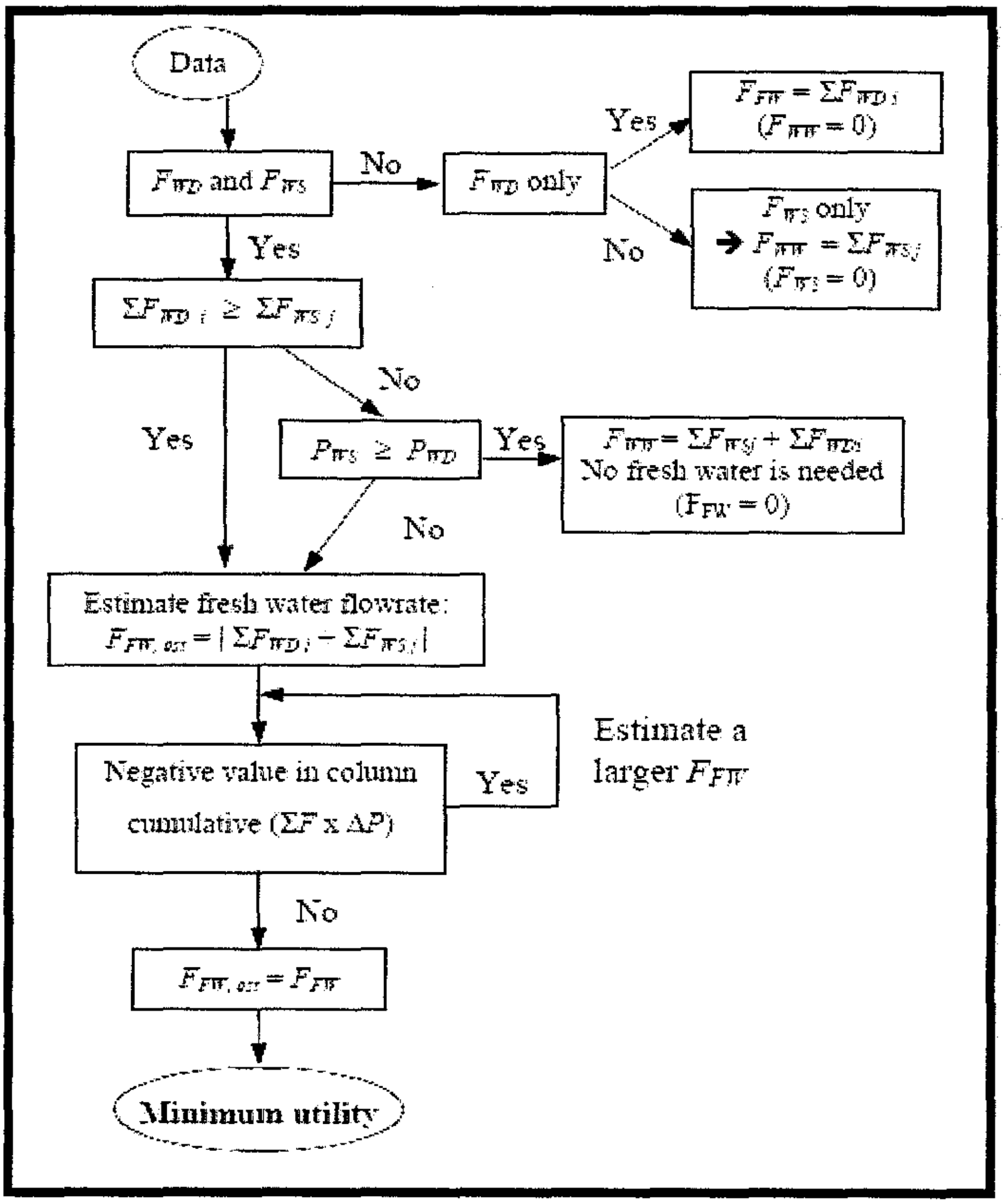


Figure 4: Overall targeting procedure by WCT

WATER NETWORK DESIGN

After the establishment of the minimum water and waste water targets, the progress will proceed with the process water network design. Two possible scopes for processes changes to further reduce the water targets, and thus lead to the saving of water consumption are including the water regeneration and equipment (hardware) modifications.

Water regeneration is involved the partial or total upgrading Water regeneration involves the partial or total upgrading of water purity using purification techniques such as adsorption, ion exchange, membrane separation, or steam stripping. The regenerated water can be either reused in other water-using processes or recycled to the same process to further reduce water consumption and wastewater generation.

However, based on Foo, there are cases where the original targeting procedure fails to determine the correct ultimate water targets. Sometimes, the concentration of the sinks is lower than outcome concentration. This results in the total source flow rate in the regenerated water region being higher than that of the sinks. For cases like these, the regenerated water region needs to be shifted to the fresh water region. The main objective for this step is to ensure that the sink(s) in the fresh water region receive feed water at its maximum allowable concentration.

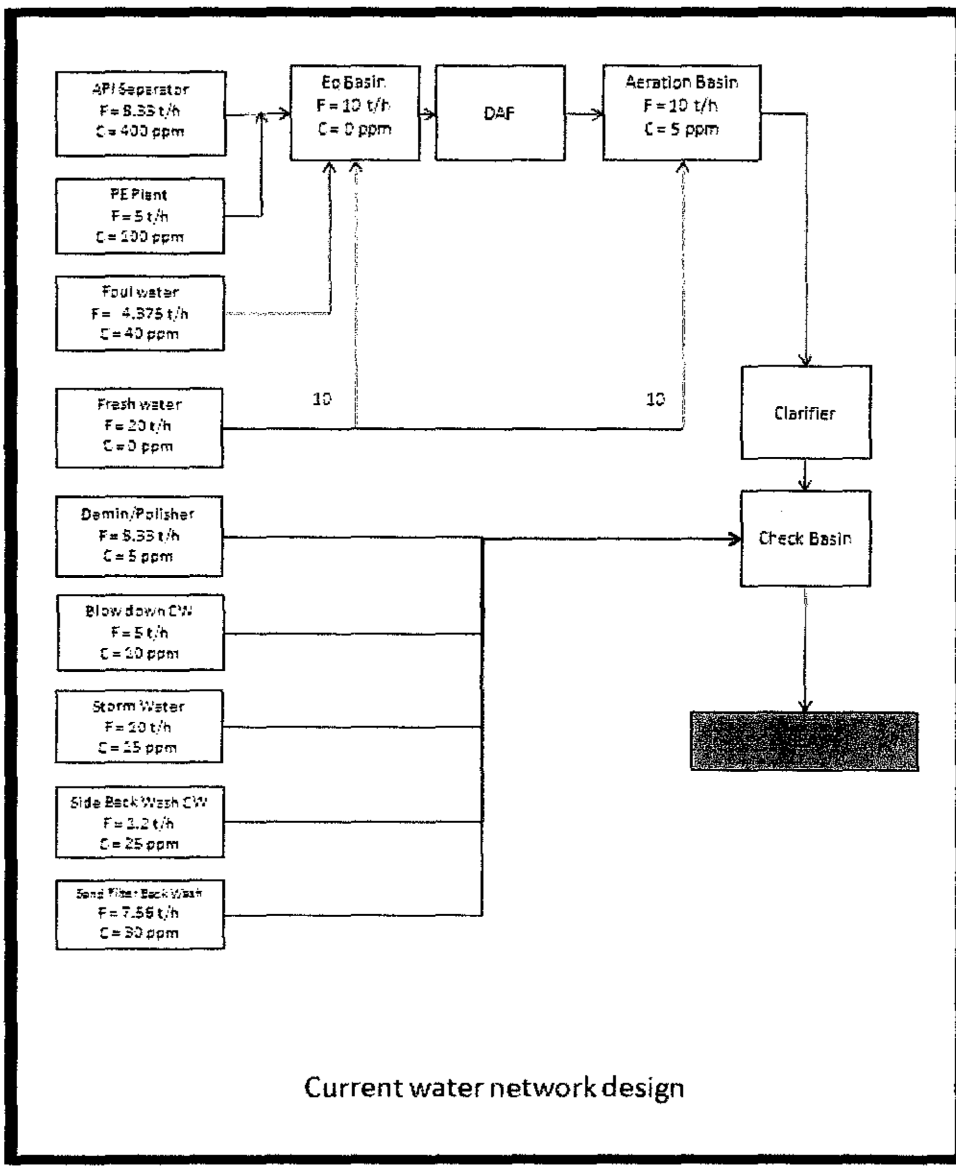
Once the research has successfully designed the new water network that will lead to the minimization of fresh water consumption, a comparison between the new water network designs with the original design of the water network needs to be done.

3.2 Project Procedure

3.2.1 Data extraction

1. Extraction of water network design at waste water treatment plant

   In this project, we need to allocate the water network at waste water treatment plant. It is important for the next step, which is to extract the data from the incoming stream of effluent into waste water treatment system.



Current water network design

Figure 5: Water network design at waste water treatment plant

2. Defining the main contaminants in the waste water effluent

In this project, we need to define the main contaminants that are needed to be cascading in the water cascade analysis. Based on the data gained, the main contaminant that is needed to be treated before the effluents could be discharged to the sea is biological oxygen demand (BOD) and chemical oxygen demand (COD).

3. Extracting data from the process flow sheet.

Water Demands, D_j		Flow rate (t/h)	Concentration (ppm)
j	Stream		BOD
1	Equalization Basin	10	0
2	Aeration Basin	10	5

Table 3: Water Demands

Water Sources, S_i		Flow rate (t/h)	Concentration (ppm)
i	Stream		BOD
1	Fresh water	20	0
2	API Separator	8.33	400
3	PE Plant	5	100
4	Foul water	4.375	40
5	Blow down CW	5	10
6	Side back wash CW	1.2	25
7	Demin / Polisher	8.33	5
8	Sand Filter Back wash	7.56	30
9	Storm water	10	15

Table 4: Water Sources

3.2.2 Designing water interval balance

1. Calculate the purity of the streams. As the concentration of pure water is one million ppm, the water purity of contaminated stream is defined as:

$$P = \frac{1000000 - C}{1000000}$$

2. Calculate the purity difference [ΔP].

$$\Delta P = P_n - P_{n+1}$$

3. List down all the flow rates for stream demands and sources. Note that water demands are written as negative values. Then add up the water demands and sources.

$$(\sum F_{WD_i} + \sum F_{WS_j}).$$

4. Identify either the stream is surplus or deficit. A positive value in this column is designating a net surplus of water presents at its respective level and the negative value is showing that a net deficit of water.
5. Refer to **Appendix A: Water Interval Table**

3.2.3 Water Cascade Analysis

1. Assume that there will be no fresh water that is going to feed into the system. (F_{FW} = 0 t/h)
2. Do the water cascading for the first time. Identify the highest value of negative. (Make it as the amount of fresh feed water needed)
3. Do another cascading and identify the pinch analysis.
4. Refer **Appendix B: Water cascade analysis**

3.2.4 Water Network Design

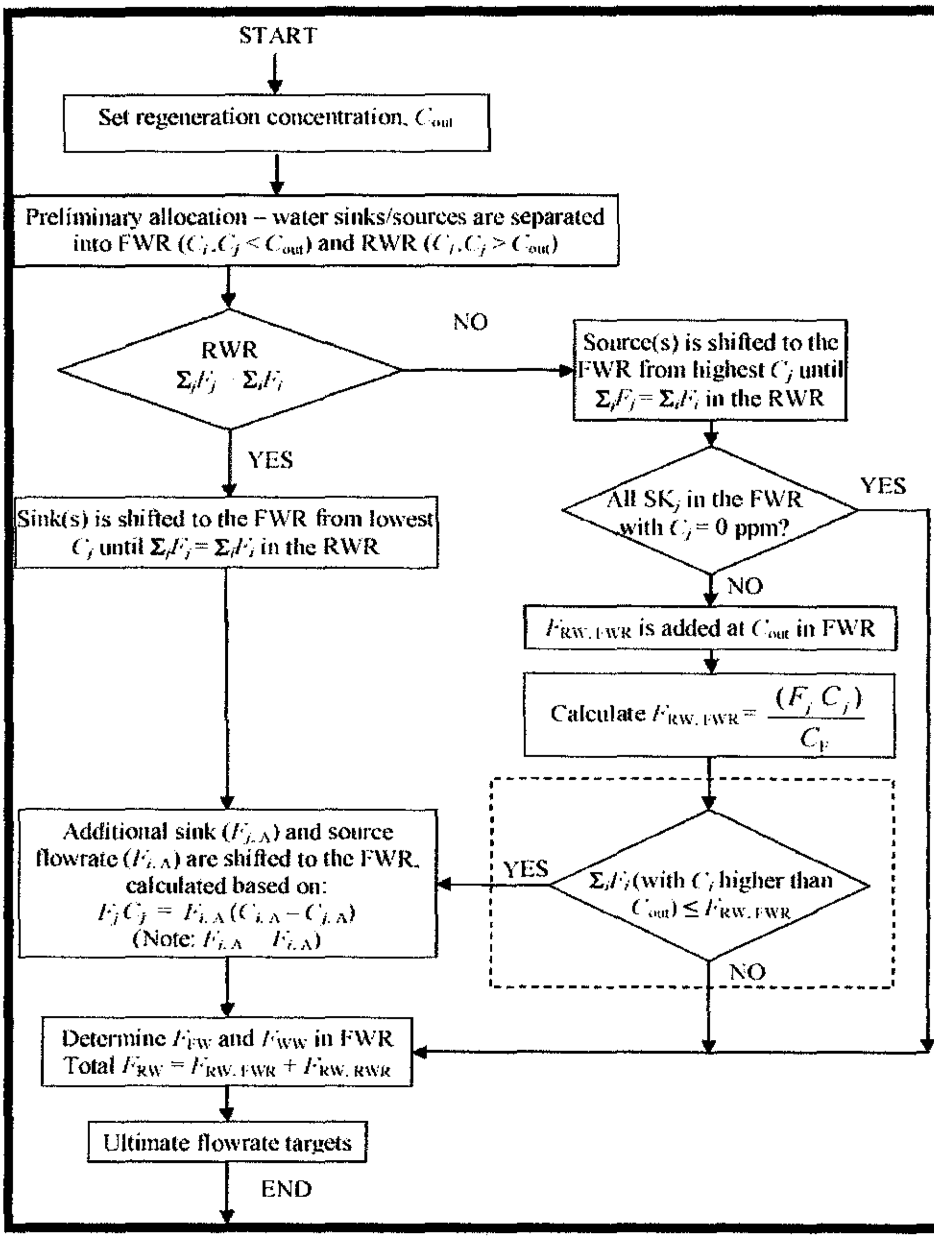


Figure 6: Water network design procedure

Water sinks and sources are firstly allocated into fresh water region (FWR) and regenerated water region (RWR) respectively, during the preliminary allocation step. The water demand that is having lower concentration than C_{out} is placed in the fresh water region; while other sinks and sources are allocated to the regenerated water region.

Since the water sink that is having the concentration lower than C_{out}, it does not require any fresh water. But, in case of the water sink sets a requirement of pure water, it means that we need to feed up pure fresh water to the sink. It is depend on the maximum allowable concentration sets up for the sinks.

Designing a water network that reuses waste water is needed dye to the shortage of fresh water and the rising cost of waste water treatment.

3.3 Gannt Chart

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Selection of Project Topic								Mid-Semester Break							
2.	Preliminary Research Work															
3.	Submission of Extended Proposal Defence															
4.	Proposal Defence															
5.	Project work continues															
6.	Submission of Interim Draft report															
7.	Submission of Interim Report															

Table 5 : FYP1 Gantt chart and Key Milestone

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Geometry design/Pre-processiong							Mid-Semester Break								
2	Solver execution															
3	Submission of Progress Report															
4	Post-Processing Activities															
5	Pre-SEDEX															
6	Submission of Draft Report															
7	Submission of Final Draft Report (Softbound)															
8	Submission of Technical Paper															
9	Viva Presentation															
10	Submission of Final Report (Hardbound)															

Table 6: FYP2 Gantt chart and Key Milestone

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

4.1.1. Find the minimum water and waste water targets

After the cascading process had been done, we could identify the pinch point of the water network design in the waste water treatment plant.

For biological oxygen demand (BOD):

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		0				
1			0			
	0.000005	-10		-0.00005000		
0.999995			-10		-0.00005000	-10
	0.000005	-1.67		-0.00005835		
0.99999			-11.67		-0.00010835	-10.835
	0.000005	5		-0.00003335		
0.999985			-6.67		-0.00014170	-9.446666667
	0.000010	10		0.00003330		
0.999975			3.33		-0.00010840	-4.336
	0.000005	1.2		0.00002265		
0.99997			4.53		-0.00008575	-2.858333333
	0.000010	7.56		0.00012090		
0.99996			12.09		0.00003515	0.87875
	0.000060	4.38		0.00098820		
0.9999			16.47		0.00102335	10.2335
	0.000300	5.16		0.00648900		
0.9996			21.63		0.00751235	18.780875
	0.999600	8.33		29.94801600		
			29.96		29.95552835	

Table 7: First attemp cascade (BOD)

For the first attempt of water cascade, we should start the cascade by assuming that there is no fresh water fed into the system. For the result, we could identify that the highest negative value that could be gained from the interval fresh water demand is -10.835.

We will start our second attempt with assuming the fresh water needed is 10.835 t/h.

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		10.835				
1			10.835			
	0.000005	-10		0.00000418		
0.999995			0.835		0.00000418	0.835
	0.000005	-1.67		-0.00000417		
0.99999			-0.835		0.00000000	9.27128E-12
	0.000005	5		0.00002083		
0.999985			4.165		0.00002083	1.388333333
	0.000010	10		0.00014165		
0.999975			14.165		0.00016248	6.499
	0.000005	1.2		0.00007682		
0.99997			15.365		0.00023930	7.976666667
	0.000010	7.56		0.00022925		
0.99996			22.925		0.00046855	11.71375
	0.000060	4.38		0.00163830		
0.9999			27.305		0.00210685	21.0685
	0.000300	5.16		0.00973950		
0.9996			32.465		0.01184635	29.615875
		8.33				
	0.999600		40.795	40.77868200	40.79052835	

Table 8: Second attemp cascade (BOD)

From the second water cascading attempt, we could identify the pinch point of this system for BOD concentration is at 3rd level of purity (P_3 = 0.99999).

The waste water produced is also decreased. Basically, the amount of waste water that is discharged to the sea is 66.66 t/h. After had been cascaded, it shows that the new system could reduce the amount of waste water produced to 40.795 t/h from 66.66 t/h.

For chemical oxygen demand (COD):

Purity, k	ΔP	F (t/h)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		0				
			0			
1		-10				
	0.000015		-10	-0.00015000		
0.999985		-1.67			-0.00015000	-10
	0.000005		-11.67	-0.00005835		
0.99998		5			-0.00020835	-10.4175
	0.000020		-6.67	-0.00013340		
0.99996		10			-0.00034175	-8.54375
	0.000020		3.33	0.00006660		
0.99994		7.56			-0.00027515	-4.585833333
	0.000020		10.89	0.00021780		
0.99992		1.2			-0.00005735	-0.716875
	0.000030		12.09	0.00036270		
0.99989		4.38			0.00030535	2.775909091
	0.000090		16.47	0.00148230		
0.9998		5.16			0.00178765	8.93825
	0.000600		21.63	0.01297800		
0.9992		8.33			0.01476565	18.4570625
	0.999200					
0			29.96	29.93603200	29.95079765	

Table 9: First attempt cascade (COD)

For the first attempt, we could identify that the highest negative value from the interval fresh water demand is -10.4715. It would be the value of the fresh water needed for the second attempt. We will assume 10.4715 t/h of fresh water is needed in doing the next cascading.

The second attempt of water cascading for the concentration of COD would be like below.

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		10.4175				
			10.4175			
1		-10				
	0.000015		0.4175	0.00000626		
0.999985		-1.67			0.00000626	0.4175
	0.000005		-1.2525	-0.00000626		
0.99998		5			0.00000000	0.0000
	0.000020		3.7475	0.00007495		
0.99996		10			0.00007495	1.87375
	0.000020		13.7475	0.00027495		
0.99994		7.56			0.00034990	5.831666667
	0.000020		21.3075	0.00042615		
0.99992		1.2			0.00077605	9.700625
	0.000030		22.5075	0.00067523		
0.99989		4.38			0.00145128	13.19340909
	0.000090		26.8875	0.00241987		
0.9998		5.16			0.00387115	19.35575
	0.000600		32.0475	0.01922850		
0.9992		8.33			0.02309965	28.8745625
	0.999200					
0			40.3775	40.34519800	40.36829765	

Table 10: Second attempt cascade (COD)

From the second water cascading attempt, we could identify the pinch point of this system for COD concentration is also at the 3rd level of purity ($P_3 = 0.99998$).

The waste water produced is also decreased. Basically, the amount of waste water that is discharged to the sea is 66.66 t/h. After had been cascaded, it shows that the new system could reduce the amount of waste water produced to 40.3775 t/h from 66.66 t/h.

4.1.2. Design new water network

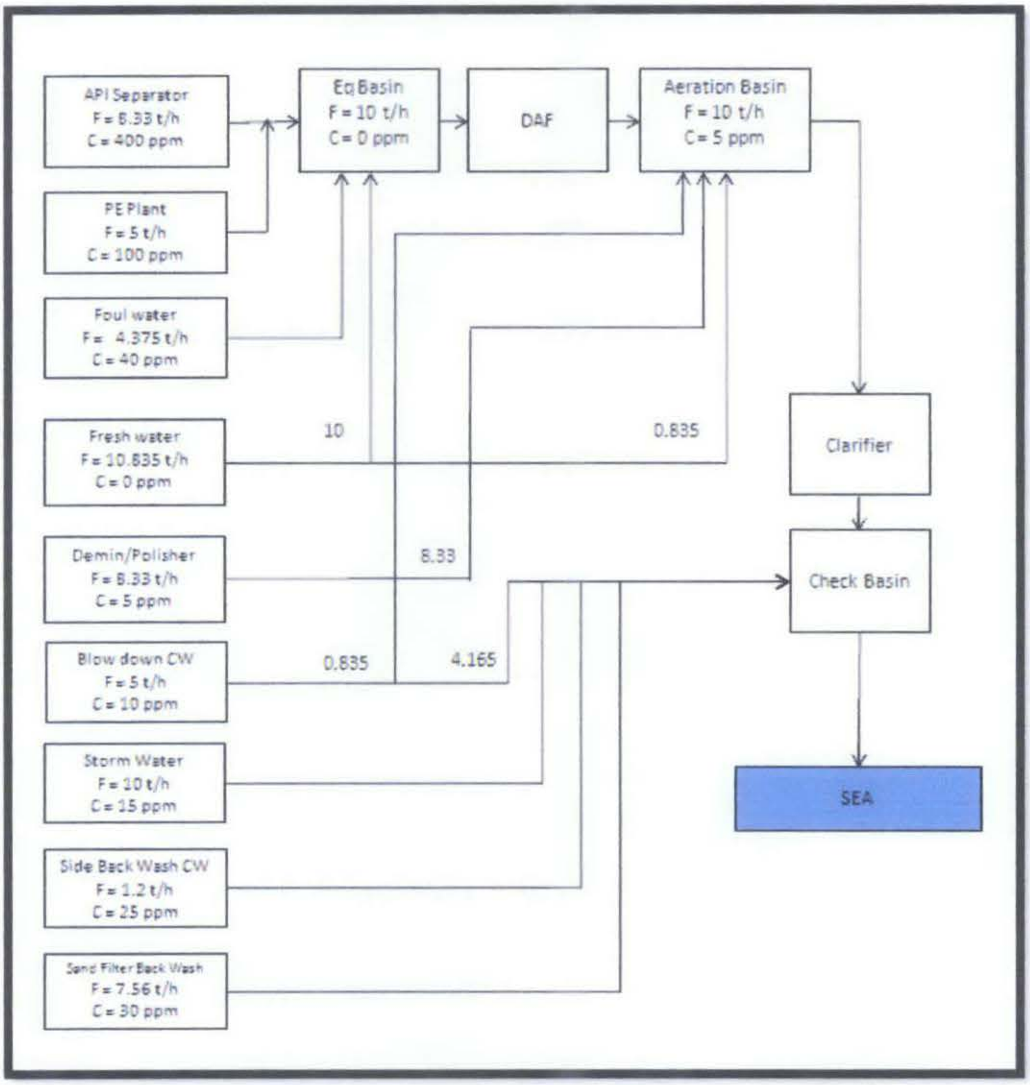


Figure 7: New water network design (BOD)

A new water network had been designed. Based on the second attempt of water cascading, it shows that, a total amount of 10 t/h of fresh water is fed into Equalization Basin. And at Aeration Basin, it is being fed by 0.835 t/h of fresh water, 8.33 t/h (C=5ppm) of Demin/Polisher streams and 0.835 t/h of cooling tower blow down (C=10ppm).

The rest is being sent to check basin before it is being discharged into the sea.

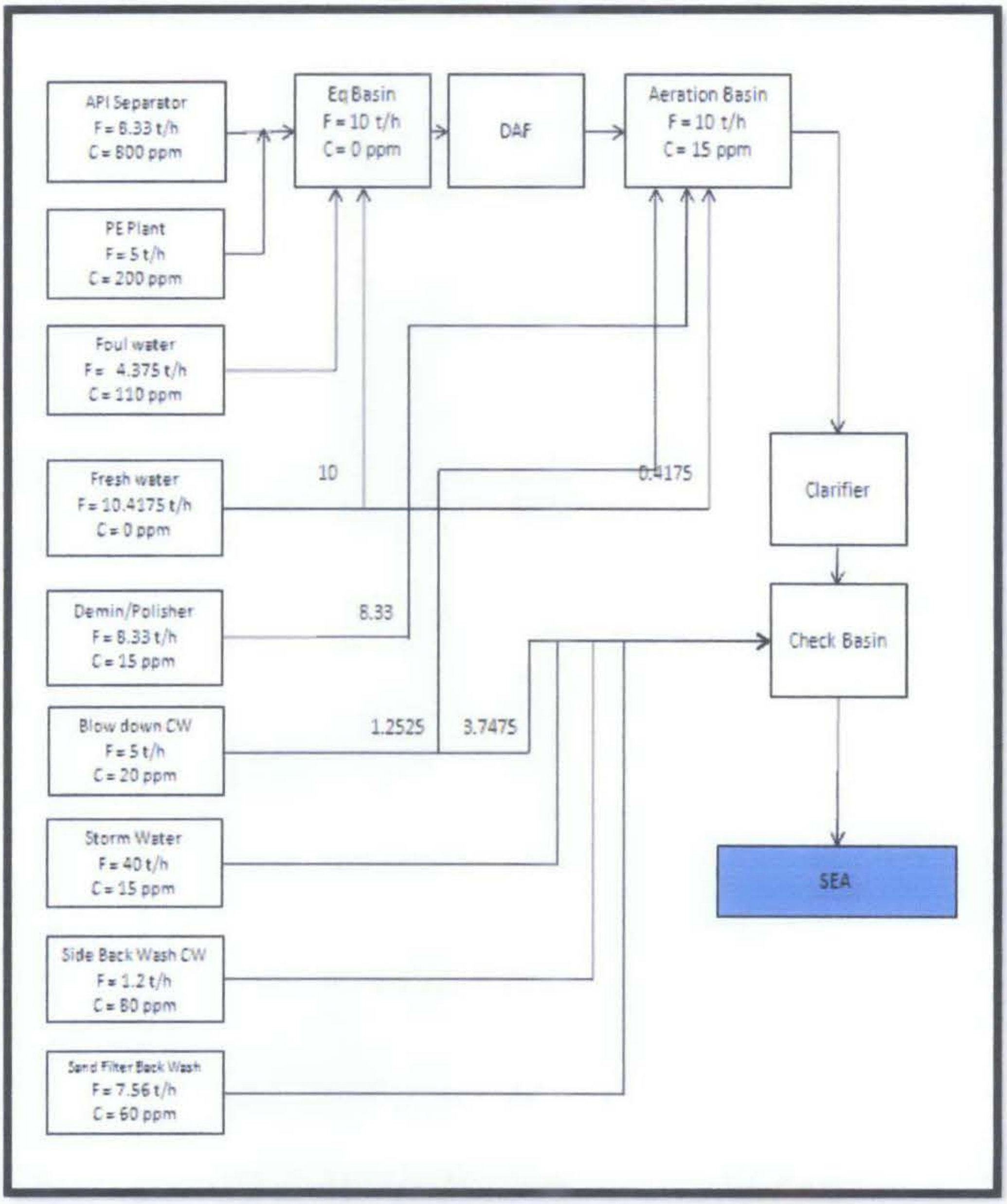


Figure 8: New water network design (COD)

A new water network had been designed. Based on the second attempt of water cascading, it shows that, a total amount of 10 t/h of fresh water is fed into Equalization Basin. And at Aeration Basin, it is being fed by 0.4715 t/h of fresh water, 8.33 t/h (C=5ppm) of Demin/Polisher streams and 1.2525 t/h of cooling tower blow down (C=10ppm).

The rest is being sent to check basin before it is being discharged into the sea. It is almost the same with the network design that is being proposed.

4.2 Discussion

By feeding 10.835 t/h fresh water for concentration BOD and 10.4715 t/h for COD, we could optimizing the consumption of fresh water by saving up to 52-54% from the amount of fresh water consume currently.

The pinch point is identified at the third purity level. Note that the pinch-causing stream for both BOD and COD cases exist at the third purity level is the water source with a total flow rate of 5 t/h. Refering to Water Interval Table, this stream is originated from cooling tower blow down.

In order to realise the pinch point and to achieve the objective, a part of the pinch-causing stream has to be allocated to a process above the pinch. The rest is allocated to the process below the pinch. Refering to Table : Second attempt cascade (BOD), 0.835 t/h of water must be sent above the pinch out of total 5 t/h from the cooling tower blow down stream. And for COD, 1.2525 t/h of the water source is sent above the pinch. While the rest is sent to the region below the pinch.

The waste water produced is also reduced by 39% from 66.66 t/h to 40.795 t/h for BOD and 40.375 t/h for COD.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In a conclusion, this project is a comprehensive research study about reusing and recycling waste water for the minimization of fresh water consumption. The project is related to the study on the water cascade analysis and designing new water network. From the studies, we could find the values of minimum water targets, which is, the overall fresh water requirement and wastewater generation for a process. The calculation and result gained is being proved and validated using water cascade analysis.

From the data extraction and cascading the water network, we could conclude that this project is achieving its objective. Both minimum fresh water targets and waste water targets could be identified. From the minimum water targets, a new water network has been designed to comply with another objective of this project, which is to optimize the fresh water consumption in minimizing the waste water discharged to the sea.

Designing a new water network that reuses waste water is needed due to the shortage of fresh water and rising cost of waste water treatement. "Reusing", "regenerating", and "regeneration and reuse" waste water reduce fresh water consumption and waste water regeneration. Waste water can also be utilized in other water demands operations, if the level of contaminent does not interfere with the water using operation. This reduces both waste water and fresh water volumes without changing the mass load of contaminants.

This project is one of our initiative to comply with the sustainability technology that is totally promoted by the Prime Minister of Malaysia, Datuk Seri Najib bin Abdul Razak.. It is hoped that this project will give the benefits to all of us in sustaining the environment for the usage of the next generation. It is actually our obligation to the society.

5.2 Recommendation

- It is fully recommended to apply the water cascade analysis in analyzing the water network design for process main stream in order to optimize the usage of fresh water and reduce the production of waste effluent
- For the other streams which are still having lower concentration of BOD, it is recommended to do some treatment to these sources of water to upgrade their purity. They could be utilized for the usage of other processes instead of just being dumped into the sea for example to be used as feed water for cooling tower.
- To use computer software called Water-MATRIX in doing the systematic technique of water cascade analysis. It is a programme that had been developed by the Process System Engineering Group UTM and is able to eliminate the tedious iterative steps during the construction of water surplus diagram.

REFERENCES

Kuriyama, T., Shiroko, K., Takama, N. and Umeda, T. (1980) "Optimal water allocation in a petroleum refinery", Computers Chem. Eng., **4**, 251–258.

Smith, R. And Wang, Y. P. (1994). "Wastewater minimisation". Chem. Eng. Sci., **49**, 981-1006.

Dhole, V. R., Ramchandani, N., Tainsh, R. A. and Wasilewski, M. (1996). "Make your process water pay for itself". Chemical Engineering **103**, 100–103.

El-Halwagi, M.M., Gabriel, F. and Harell, D., 2003, Rigorous graphical targeting for resource conservation via material recycle/reuse networks, Ind Eng Chem Res, 42: 4319–4328.

Hallale, N. (2002). "A new graphical targeting method for water minimisation". Adv. Env. Res., **6** (3), 377–390.

Foo, C. Y., Manan, Z. A. and Tan, Y. L. (2002). "Water minimisation by pinch technology – water cascade table for minimum water and wastewater targeting". *9th Asian Pacific Confederation of Chemical Engineering (APCChE 2002) Congress.*

Foo, C. Y., Manan, Z. A. and Tan, Y. L. Water Minimisation by Pinch Technology – Water Cascade Table for Minimum Water and Wastewater Targeting

Foo, C. Y., Manan, Z. A. and Tan, Y. L. Targeting the Minimum Water Flow Rate Using Water Cascade Analysis Technique.

El-Halwagi, M.M. (1997). Pollution prevention through process integration: systematic design tools (Volume 1). Academic Press.

Foo, D.C.Y., 2007, Flowrate targeting for threshold problems and plant-wide integration for water network synthesis, Journal of Environmental Management (in press).

Boland, D. W., Guy A. R., Hewitt, D., Marshall, R. H., Townsend, B.L. and Thomas, G. F. (1982). " A User Guide on Process Integration for the Efficient Use of Energy." Rugby: Icheme.

Foo, C. Y., Manan, Z. A. and Tan, Y. L. (2004), Targeting the minimum water flowrate using water cascade analysis technique, AIChE J, 50(12): 3169–3183.

Foo, C. Y., Manan, Z. A. and Tan, Y. L. (2005), Water pinch analysis for an urban system: a case study on the Sultan Ismail Mosque at UTM, Desalination 194 (2006): 52-68

Foo, D.C.Y., Manan, Z.A. and Tan, Y.L., (2006), Use cascade analysis to optimize water networks, Chemical Engineering Progress, 102(7): 45–52.

Foo, D.C.Y., Ng, D. K. S., Tan, R. R. and Tan, Y. L. (2008), Extension of Targeting procedure for "Ultimate Flowrate Targeting with Regeneration Placement" Ng et al.,Chem. Eng. Res. Des., 85 (A9): 1253–1267

Foo, D.C.Y., Ng, D. K. S., Tan, R. R. and Tan, Y. L. (2007), Ultimate Flowrate Targeting With Regeneration Placement, Trans IChemE, Part A : 1253-1267

APPENDICES

Appendix A: Water Interval Table

Column	1	2	3	4	5	6	7
Interval, n	**Concentration, Cn (ppm)**	**Purity, Pn**	**ΔP**	**∑ D,j (t/h)**	**∑ S,i (t/h)**	**∑ D,j (t/h) + ∑ S,i (t/h)**	**Net water source/ demand**
	0	1		-10		-10	Demand
1			0.0000050				
	5	0.999995		-10	8.33	-1.67	Demand
2			0.0000050				
	10	0.99999			5	5	Source
3			0.0000050				
	15	0.999985			10	10	Source
4			0.0000100				
	25	0.999975			1.2	1.2	Source
5			0.0000050				
	30	0.99997			7.56	7.56	Source
6			0.0000100				
	40	0.99996			4.38	4.38	Source
7			0.0000600				
	100	0.9999			5.16	5.16	Source
8			0.0003000				
	400	0.9996			8.33	8.33	Source
9			0.9996000				
	1000000	0					

Table 11: Water Interval Balance for BOD

Column	1	2	3	4	5	6	7
Interval, n	Concentration, Cn (ppm)	Purity, Pn	ΔP	∑ D,j (t/h)	∑ S,i (t/h)	∑ D,j (t/h) + ∑ S,i (t/h)	Net water source/ demand
	0	1		-10		-10	Demand
1			0.0000150				
	15	0.999985		-10	8.33	-1.67	Demand
2			0.0000050				
	20	0.99998			5	5	Source
3			0.0000200				
	40	0.99996			10	10	Source
4			0.0000200				
	60	0.99994			7.56	7.56	Source
5			0.0000200				
	80	0.99992			1.2	1.2	Source
6			0.0000300				
	110	0.99989			4.38	4.38	Source
7			0.0000900				
	200	0.9998			5.16	5.16	Source
8			0.0006000				
	800	0.9992			8.33	8.33	Source
9			0.9992000				
	1000000	0					

Table 12: Water Interval Balance for COD

Appendix B: Water Cascade Analysis

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		0				
			0			
1		-10				
	0.000005		-10	-0.00005000		
0.999995		-1.67			-0.00005000	-10
	0.000005		-11.67	-0.00005835		
0.99999		5			-0.00010835	-10.835
	0.000005		-6.67	-0.00003335		
0.999985		10			-0.00014170	-9.446666667
	0.000010		3.33	0.00003330		
0.999975		1.2			-0.00010840	-4.336
	0.000005		4.53	0.00002265		
0.99997		7.56			-0.00008575	-2.858333333
	0.000010		12.09	0.00012090		
0.99996		4.38			0.00003515	0.87875
	0.000060		16.47	0.00098820		
0.9999		5.16			0.00102335	10.2335
	0.000300		21.63	0.00648900		
0.9996		8.33			0.00751235	18.780875
	0.999600		29.96	29.94801600	29.95552835	

Table 13: Water Cascade Analysis 1 for BOD

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		10.835				
			10.835			
1		-10				
	0.000005		0.835	0.00000418		
0.999995		-1.67			0.00000418	0.835
	0.000005		-0.835	-0.00000417		
0.99999		5			0.00000000	0
	0.000005		4.165	0.00002083		
0.999985		10			0.00002083	1.388333333
	0.000010		14.165	0.00014165		
0.999975		1.2			0.00016248	6.499
	0.000005		15.365	0.00007682		
0.99997		7.56			0.00023930	7.976666667
	0.000010		22.925	0.00022925		
0.99996		4.38			0.00046855	11.71375
	0.000060		27.305	0.00163830		
0.9999		5.16			0.00210685	21.0685
	0.000300		32.465	0.00973950		
0.9996		8.33			0.01184635	29.615875
	0.999600		40.795	40.77868200	40.79052835	

Table 14: Water Cascade Analysis 2 for BOD

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		0				
			0			
1		-10				
	0.000015		-10	-0.00015000		
0.999985		-1.67			-0.00015000	-10
	0.000005		-11.67	-0.00005835		
0.99998		5			-0.00020835	-10.4175
	0.000020		-6.67	-0.00013340		
0.99996		10			-0.00034175	-8.54375
	0.000020		3.33	0.00006660		
0.99994		7.56			-0.00027515	-4.585833333
	0.000020		10.89	0.00021780		
0.99992		1.2			-0.00005735	-0.716875
	0.000030		12.09	0.00036270		
0.99989		4.38			0.00030535	2.775909091
	0.000090		16.47	0.00148230		
0.9998		5.16			0.00178765	8.93825
	0.000600		21.63	0.01297800		
0.9992		8.33			0.01476565	18.4570625
	0.999200					
0			29.96	29.93603200	29.95079765	

Table 15: Water Cascade Analysis 1 for COD

Purity, k	ΔP	F (kg/s)	Cumulative water source/ demand	Pure water surplus/deficit	Cumulative pure water surplus/deficit	Interval fresh water demand
		10.4175				
			10.4175			
1		-10				
	0.000015		0.4175	0.00000626		
0.999985		-1.67			0.00000626	0.4175
	0.000005		-1.2525	-0.00000626		
0.99998		5			0.00000000	0.0000
	0.000020		3.7475	0.00007495		
0.99996		10			0.00007495	1.87375
	0.000020		13.7475	0.00027495		
0.99994		7.56			0.00034990	5.831666667
	0.000020		21.3075	0.00042615		
0.99992		1.2			0.00077605	9.700625
	0.000030		22.5075	0.00067523		
0.99989		4.38			0.00145128	13.19340909
	0.000090		26.8875	0.00241987		
0.9998		5.16			0.00387115	19.35575
	0.000600		32.0475	0.01922850		
0.9992		8.33			0.02309965	28.8745625
	0.999200					
0			40.3775	40.34519800	40.36829765	

Table 16: Water Cascade Analysis 2 for COD