Optimization of Heavy Metal Wastewater Treatment System

By

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I.D. No. : 1571

Dissertation submitted in partial fulfillment of
the requirement for
Bachelor of Engineering (Hons)
(Chemical Engineering)

July 2003

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CERTIFICATE OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement of
BACHELOR OF ENGINEERING (HONS)
(CHEMICAL ENGINEERING)

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CERTIFICATE OF ORIGINALITY

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

Yong Jing Ren

ABSTRACT

Semiconductor industry is one of the most rapid developed industries. Heavy metal wastewater that being produced from the operation of this industry requires treatment before it could be discharged into the environment to avoid pollution. The costs of treatment for the heavy metal wastewater is rather significant and proportional to the amount of water that to be treated. Conventional centralized treatment system requires waste streams to undergo each treatment system resulting in unnecessary increase in capital and operation costs. Decentralized wastewater treatment system offers advantages in reducing the amount of wastewater that going through a unit operation by introducing bypassing waste stream that would only combined with the primary stream when necessary. Centralized wastewater treatment system always yields effluent quality that greatly exceeds the required discharge requirements. Decentralized treatment system would treat the wastewater to sufficient requirement effluent that to be released into the environment. This case study is based on the centralized and decentralized (optimization) wastewater treatment system. Excel Spreadsheet simulation of the vessel prize of the wastewater treatment system is done to determine the maximum savings that could be achieved through this concept. Process sensitivities such as effects of bypassing and changes of removal ratio to the total cost with reference to the targeted effluent quality are evaluated. The more decentralize the system, the more savings could be achieved. The degree of savings however is determined by the effluent quality constraints where it must achieve Environmental Quality (Sewage and Industrial Effluents) 1979 Standard B. The results of the simulation is tabulated and with serve as guide for the optimization of the heavy metal wastewater treatment system. The final design of the system is based on the best savings that could be achieved to achieve the treated effluent quality. It will also be chosen based on its practical applicability in industry.

ACKNOWLEDGEMENT

This project was done in collaboration of the School of Chemical Engineering of University of Technology PETRONAS and VEOLIA Water System Industrial Services (M) Sdn. Bhd.

I would like to express my greatest gratitude to Dr. Kamarul Ariffin Amminudin and Ms. Tang Soo Nee, Application Engineer of VWS Industrial Services for their guidance and supervision during my studies. Under their immense guidance throughout the study, I was introduced to different approach and ways to solve the problems in my research. Their vast knowledge has provided a foundation in developing my research project, which could be very practical and useful in my future career.

Besides, I would like to thank Pn. Putri, (Water and Wastewater Engineering Lecturer) for her knowledge on water and wastewater treatment. Her knowledge in that subject was my root to pursue my findings for this project.

Pn. Anis, Coordinator of Chemical Final Year Research Project deserved special recognition and appreciation for her effort in providing arrangement, establishing genuine contact and understanding between students and Chemical Final Year Research Project Committee of Universiti of Teknologi Petronas (UTP).

Last but not least, I would like to acknowledge the cooperation of my Industrial Training host company, VEOLIA Water System Industrial Services (M) Sdn. Bhd. especially the Project Department for their continued patience, understanding, encouragement and support to lead me out of the woods when I was lost.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Water is universal solvent. It is one of the most important aspects in industries. Water is used in industries because it is cheap, redundant and easy to handle. At the same time, wastewater is produced during the production of industry usage. For Semiconductor industry, the wastewater produced contained highly concentrated heavy metal and wafer saw waste. These highly toxic wastewater need to be treated before it could be released to the environment. Hence, wastewater treatment industry has the potential to become another major force in industry in the near future. Heavy Metal Ion Exchange Wastewater Treatment Plant would be suitable in treating heavy metal wastewater rather than conventional Batch Reactor because in semiconductor industry the production runs at a 24 hourly basis and this would generate wastewater at all time. The implementation of Batch Reaction would be unpractical and thus, introducing a Continuous Wastewater Treatment Plant would be most suitable. The application of Heavy Metal Ion Exchanger could be rather expensive in terms of its operating costs and capital costs. Hence, it is ideal to optimize the performance of the Heavy Metal Ion Exchange Wastewater Treatment Plant.

1.2 Problem Statement

The design requirement for a semiconductor plant situated in a non-water catchments area is being listed, where a new wastewater treatment plant is being put on tender. Parameters of the wastewater treatment plant are stated in Table 1.1 :

Design Capacity

40 m^3/hr Industrial Wastewater Treatment Plant operates at 12 hourly basis

Combined Rinse Waste Characteristics	
pH	1.0 – 2.5
BOD_5	< 2 mg/l
COD	< 10 mg/l
SS	< 30 mg/l
Mercury	< 0.001mg/l
Cadmium	< 0.03 mg/l
Copper	< 90.0 mg/l
Cyanide	< 0.05 mg/l
Lead	< 1.62 mg/l
Chromium, Trivalent	< 0.01 mg/l
Manganese	< 0.02 mg/l
Nickel	< 35.0 mg/l
Tin	< 4.00 mg/l
Zinc	< 1.75 mg/l
Boron	< 0.40 mg/l
Fe	< 0.56 mg/l
Phenol	< 0.07 mg/l
Free Chlorine	< 0.10 mg/l
Sulfide	< 0.01 mg/l

Table 1.1 Wastewater Influent Characteristics

The cost of wastewater treatment is relatively high. It is known that the cost of wastewater treatment is directly proportional to the amount of wastewater treated. Reduction of wastewater quantity is impossible due to production constraints in semiconductor industry. The project will examine the optimization of the wastewater treatment plant by introducing bypass to the conventional system and other alternatives that could significantly reduce the capital costs of the wastewater treatment plant. Total capital costs of the wastewater treatment plant will be evaluated and compared to the conventional arrangement of wastewater treatment plant. The results will be tabulated and the in-depth analysis on the significance of the designed system will be discussed.

1.3 Objectives and Scope of Study

1. To design a wastewater treatment plant that is practical and cost effective in industrial application.

2. To identify the suitable unit operation for the treatment system by referring to efficiency, reliability and costs.

3. To analyze the difference between conventional treatment systems with optimized treatment systems.

4. To analyze the process sensitivities of each option based on the operating cost, capital cost and the effluent discharge standard.

5. To identify the solution for solving bottleneck problems in the optimized wastewater treatment system.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Water consumption in industry and its treatment is a continuous process. Fresh or pre-treated water is used in industrial production, and hence producing wastewater. Wastewater will then be treated by using onsite wastewater treatment plant before it is discharged into the environment such as rivers and drains. The water will then complete the cycle by returning to the production as fresh water.

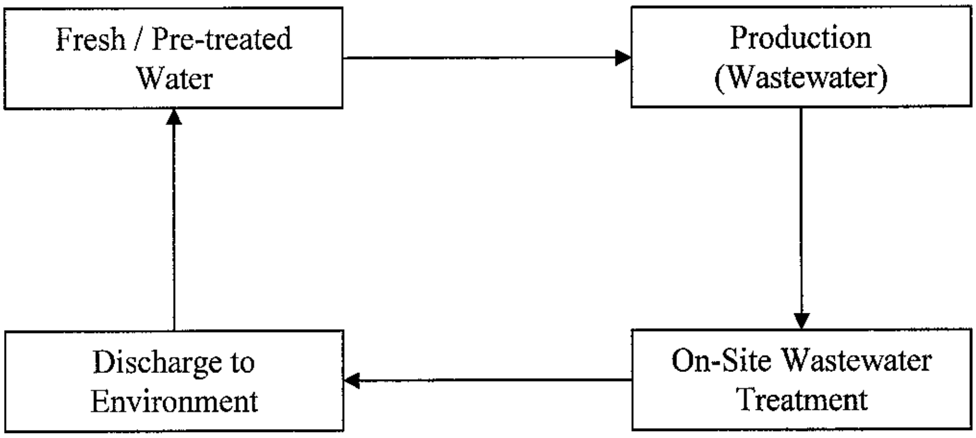

Figure 2.1 Industrial Water Cycle

There are two routed that could be manipulated to reduce the cost of wastewater treatment, namely to reduce the water consumption in production and to implement cheaper alternatives or treatment systems in wastewater treatment. Since the usage of water in production is almost impossible to be reduced, this study is focusing on the ways to manipulate the treatment system (unit operations) of the wastewater treatment plant.

Heavy Metal Ion Exchange Wastewater Treatment Plant is most suitable for the preset problem statement, which the contaminant involved are mainly highly toxic heavy metals. The treatment system that being design need to comply with the Environmental Quality (Sewage and Industrial Effluents) Regulation 1979, Standard B.

Conventional Heavy Metal Ion Exchanger Wastewater Treatment Plant consists of two main treatment sections; combined rinse wastewater and wafer saw waste treatment and spent concentrated chemical treatment.

1. Combined rinse waste and wafer saw waste treatment
    - Pre pH Adjustment Package
    - Sand and Activated Carbon Filtration System (Pre-Treatment)
    - Heavy Metal and Arsenic Exchanger Package (Ion Exchange)
    - Final pH Adjustment Package

2. Spent Concentrated Chemical Treatment
   (Regeneration of Ion Exchange Resins and spent acid)
    - Electrowinner System
    - Batch Treatment Chemical Precipitation Package
    - Sludge Thickening System
    - Filter Press Dewatering System

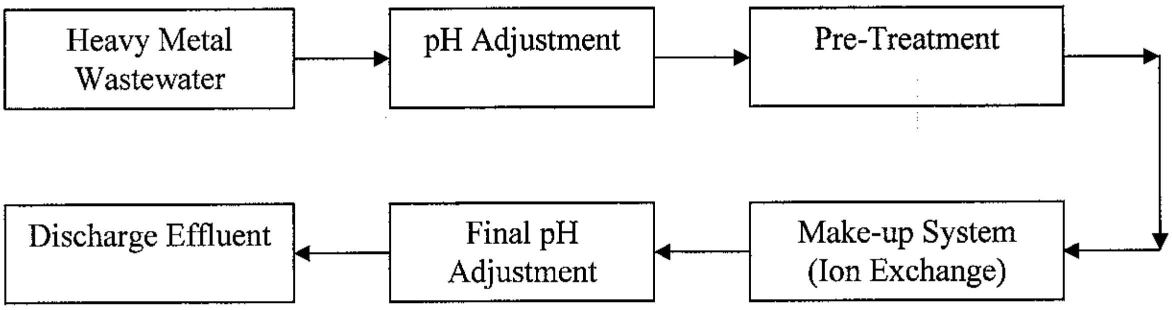

Figure 2.2 Conventional Heavy Metal Wastewater Treatment System

The conventional treatment system consists of three main units, the primary treatment units, secondary treatment units and the tertiary treatment units. Primary treatment units include pre-treatment such as filtration of suspended solids. Secondary treatment is the main treatment unit, which is defined as the make up system. The make up system used is the heavy metal ion exchanger. Final pH adjustment is the tertiary treatment where the effluent pH is adjusted to the required pH before it is discharged.

The makeup system of this wastewater treatment plant is Ion Exchanger, which could effectively remove the contaminants (heavy metals) of the wastewater. The Exchange technical specifications of each unit operations (sand filter, activated carbon filter and Ion Resins) are attached at the appendix section.

The combination of decentralized and centralized wastewater treatment plant is rather a new idea currently. The main idea of this concept is to systematically exploit the probability to segregate the wastewater stream to reduce the capacity and combined them only when it is necessary. With this concept, we could significantly reduce the capacity of the wastewater stream, hence reducing the loading and size of the unit operations, thus reducing the capital cost of the wastewater treatment plant.

In this project, pricing of each unit operation is obtained from VWS Industrial Services and is subjected to change from time to time. All costs is calculated in Ringgit Malaysia. Material balance of each stream is carried out during the calculation of the contaminant concentration.

CHAPTER 3
METHODOLOGY

The project was carried out by determining the best suitable unit operation for the heavy metal wastewater treatment plant. The ion-exchange treatment system was selected due to its efficiency and reliability to adsorb the total dissolved heavy metals in the wastewater. Other treatment such as activated sludge and sequential batch reactor are not suitable due to the highly toxic wastewater. Pre-treatment was included to filter the total suspended solids and adsorb the chlorine content in the wastewater. This is to reduce the turbidity of the wastewater and provide a suitable condition (pH and turbidity) for ion exchange to occur efficiently. Besides, pre-treatment also help to preserve the lifetime of the ion exchange resins.

An early based case of the treatment system was constructed. The base case consists of the incoming wastewater stream, pre-treatment; make up system and the final discharge quality. The parameters (removal ratio) of each unit operation are obtained and calculation of the final discharge quality of the treated effluent is done. The tabulated results is then being compared with the standard quality that to be achieved. Possibility of bypass stream is then being studied and simulation is done by using Microsoft Excel. The result obtained is then being compared again with the standard quality of discharged effluent. Material balance calculation is carried out during the simulation process. Maximum bypass flowrate of each stream is calculated with respect to the acceptable effluent quality.

The final stage of the project is to determine the total costs of the designed wastewater treatment plant. Sizing of each unit operation is made with respect to its capacity. Price comparison of the conventional and the optimized treatment plant is being made and the best design with respect to the capital cost is chosen. The advantages and disadvantageous of each plant is also being discussed.

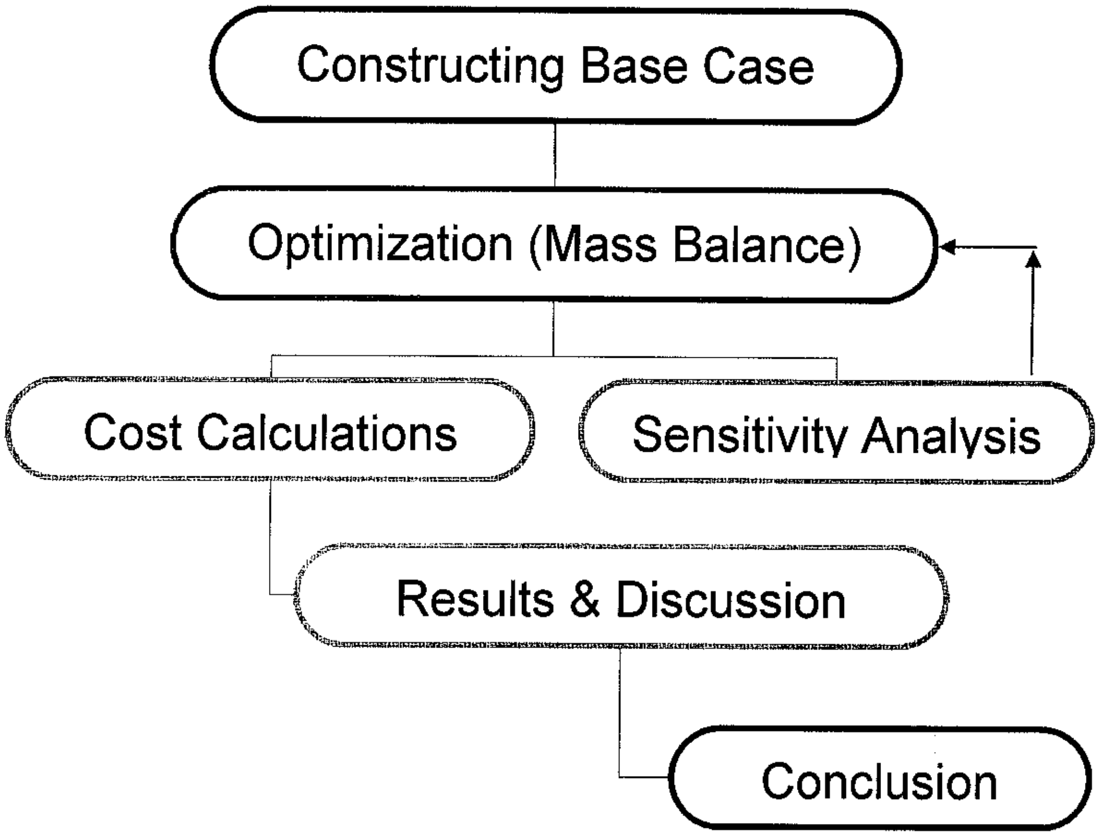

Figure 3.1 Project Flow Diagram

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Centralized Wastewater Treatment System

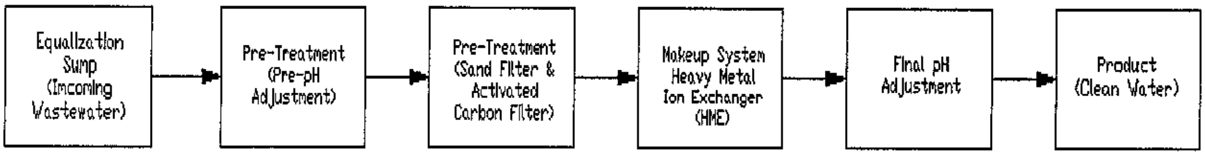

Figure 4.1 : Conventional Centralized Wastewater Treatment System

The conventional Wastewater Treatment System consists of the equalization of the incoming wastewater, Pre-pH Adjustment Package, Pre-Treatment of Sand and Activated Carbon Filter, the Make-up System of Heavy Metal Ion-Exchanger and Final pH Adjustment before the release of clean effluent. In order to simplified and narrow down the scope of study, a few assumptions had been made:

i) Treatment stage that does not involve sizing and critical sensitivity issues is eliminated, assuming that the cost of the unit treatment will remain constant.

ii) There is no loss of water quantity during the treatment system.

iii) Heavy metals of the feed have been scoped down to Copper only since it is the majority contaminant.

iv) Safety factor percentage is assumed to remain constant with respect to each alternative.

From the previous assumptions, the base case of this case study is built:

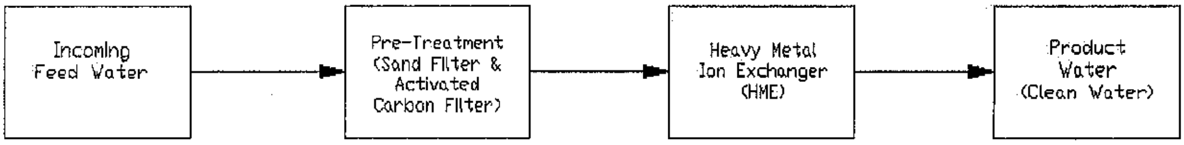

Figure 4.2 : Base Case of Centralized Wastewater Treatment System

The arrangement of the unit operations is showed in figure 4.3, the pre-treatment system consists of two pressure vessels of Sand Filter and two Activated Carbon Filter vessels arranged in parallel. The Heavy Metal Ion Exchanger consists of two more pressure vessels. The total pressure vessels in the system will be six, with three each arranged in parallel.

Simulation and sizing of each unit operation of the based case is carried out and showed in Table 4.1.

Sand Filter							
Feed	Vessels	Flowrate	Velocity	Radius	Diameter	Costs/Unit	Total Costs
40	2	20	12	0.7283	1.4566	13600	27200
Activated Carbon Filter							
40	2	20	12	0.7283	1.4566	13350	26700
Heavy Metal Ion Exchanger							
40	2	20	17	0.6211	1.2422	20000	40000
Total							93900

Table 4.1 : Calculation of Pressure Vessels Costs for Conventional System

Feed (Incoming Wastewater and Vessel Flowrate) - m^3/hr,
Linear Velocity - m/hr,
Vessel Diameter, Radius - m
Costs - Ringgit Malaysia (RM)

The detail of the costing of each vessel type and specification are attached in the appendix. The main criterion of this research project is with respect to the capital costs of the newly proposed WWTP. Hence, other unit process such as pre-pH adjustment package and the final pH adjustment package is neglected and assumed as constant.

Total Capital Costs = Vessel Costs + Constant Eqn.4.1

Constants: Pre, Final pH Adjustment Package, instruments and the control system

Hence, total capital cost is directly proportional to the Vessel Costs.

4.2 Decentralized Wastewater Treatment System

The decentralized wastewater treatment system has the function of reducing the incoming feed to the unit operation by splitting the streams (eg. By-pass). In this project, bypass stream was introduced to the treatment system. Bypass was introduced to the feed stream of the pre-treatment and the heavy metal ion exchanger.

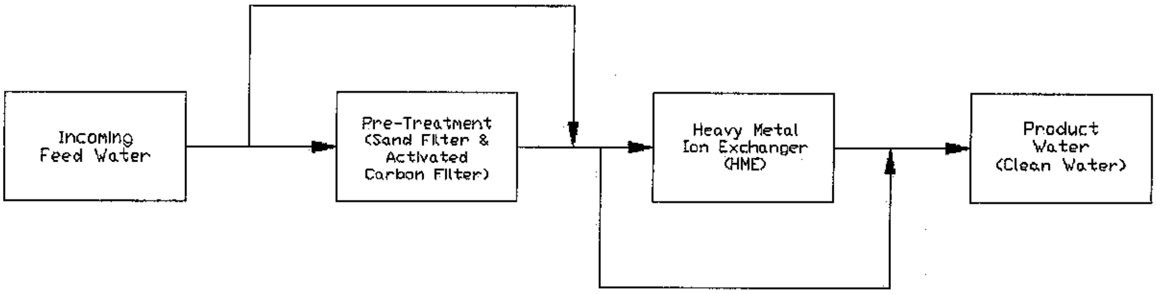

Figure 4.3 : Optimized Wastewater Treatment System (Stage 1)

In this project, the removal ratio of each unit operations and the targeted value of parameters to reach were set and are presented in Table 4.2.

Parameters	Feed In	Removal Ratio	Effluent	Std. B
Copper ppm	90	99.5%	0.45	<1.0
Turbidity (NTU)	25	99%	0.25	2
Chlorine ppm	0.1	97%	0.003	<0.01

Table 4.2 : Removal Ratio and Targeted Parameters to Comply

There are six proposed alternatives (Table 4.3) for the optimization of the plant. They are identified and simulated to determine the best solution. The simulation of the optimized wastewater treatment system is done by referring to Figure 4.4

Alternative	By-pass (m^3/hr)	Removal Ratio (%)		
		Turbidity	Chlorine	Heavy Metal (Cu)
A	-	95	95	99.5
B	-	97	97	99.5
C	-	99	97	99.5
D	20	99	97	99.5
D1	25	99	97	99.5
D2	30	99	97	99.5

Table 4.3 : Alternatives for Optimizing Wastewater Treatment System

The simulation was done by using Excel Spreadsheet. The removal ratio is important in determining the amount of wastewater flowrate that could be by-pass without treatment but still would comply with the pre-determined standards.

The formulas used are as below:

$X = Y1 + Y2$

X = Water Quality at Make-up System Inlet

$Y1$ = Water Quality at Bypass Stream

$Y2$ = Water Quality at Outlet of Pre-treatment Units

Z = Water Quality at Discharge Effluent

With Recycle Stream

$X = (RX_1 + FX_2) / (R + F)$

Incoming Influent quality is determined before general mass balance could be done.

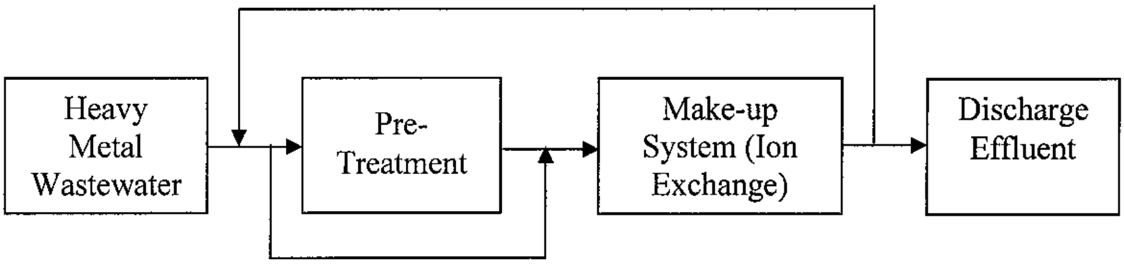

Figure 4.4 : Optimized Wastewater Treatment System (Final Base Case)

The simulation is done by using the mass balance equation with sufficient information such as the removal ratio and the price list. The simulation was done by referring to the cost versus effluent quality issue. The effluent quality was set as constant for all alternatives to ease the analysis of the simulated results.

The results as tabulated in Table 4.4.

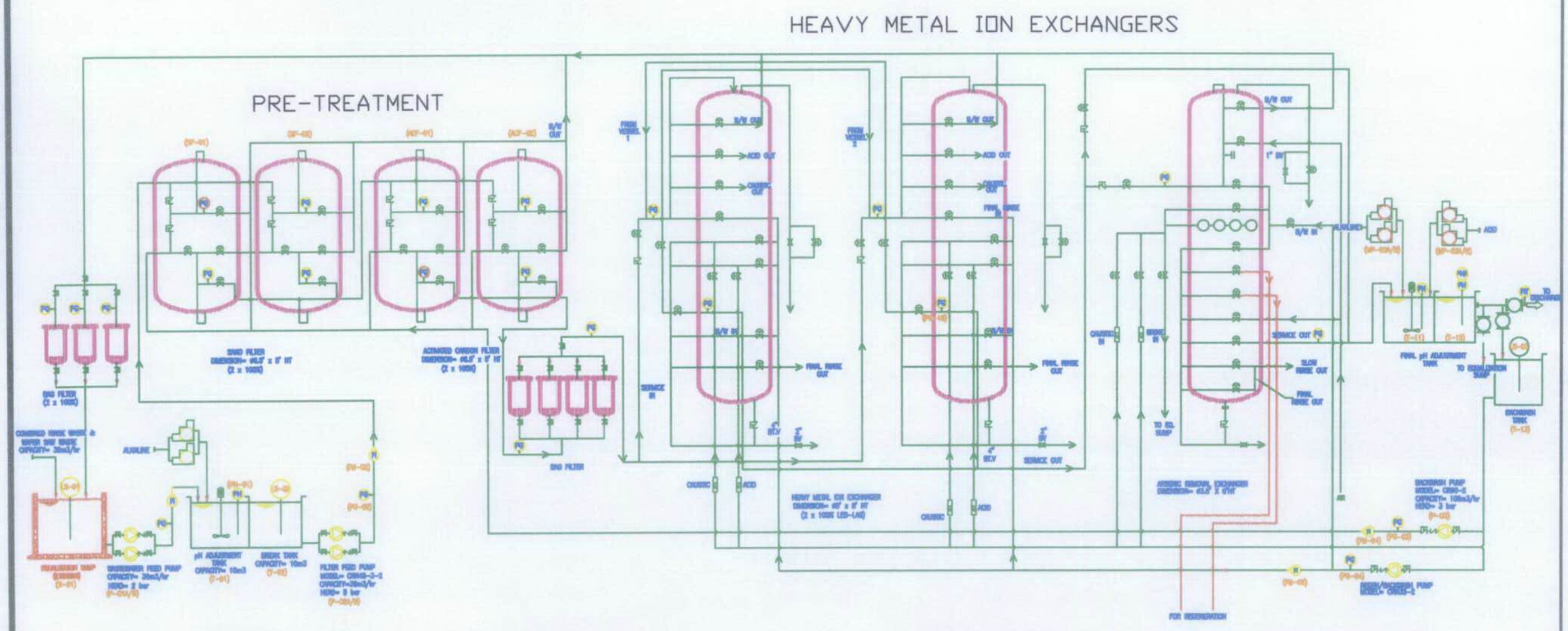

FIGURE 4.4 CONVENTIONAL HEAVY METAL WASTEWATER TREATMENT PLANT

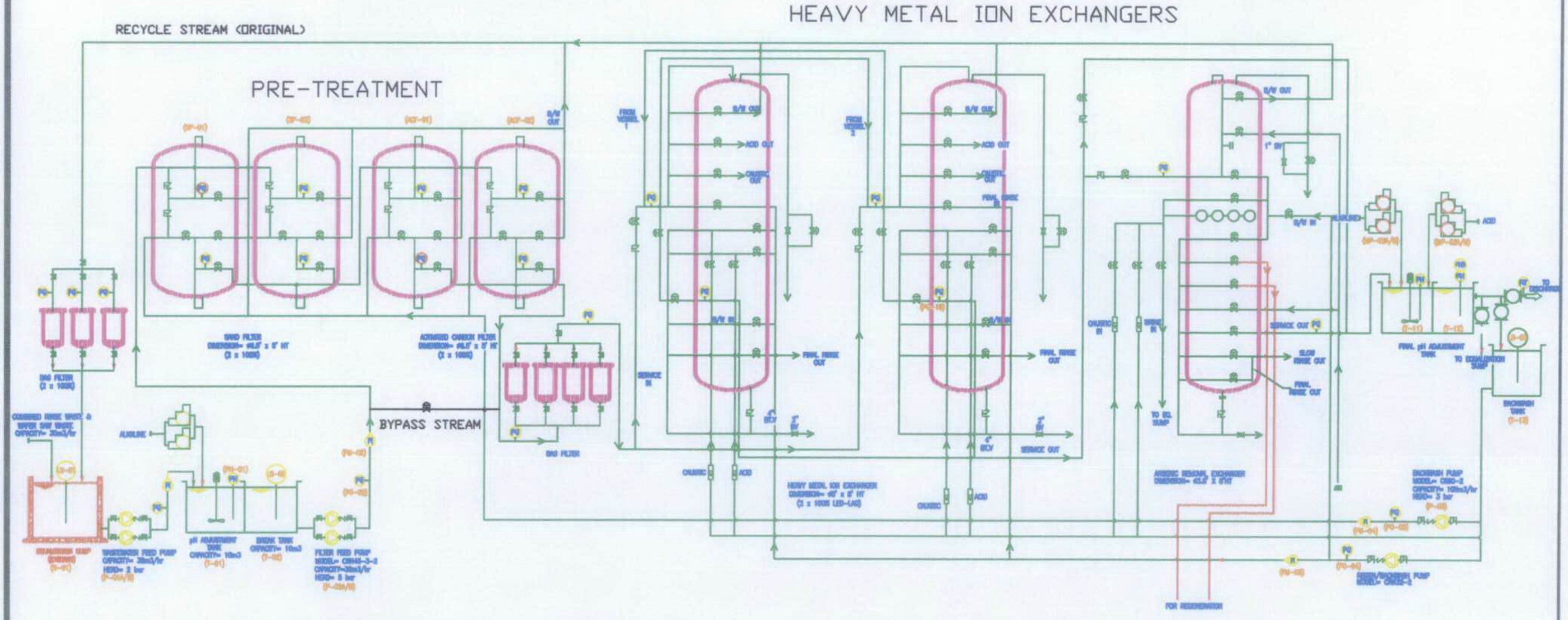

FIGURE 4.5 OPTIMIZED HEAVY METAL WASTEWATER TREATMENT PLANT

Feed In	No.	Bypass	Feed Flowrate	V	Vessel Diameter	Feed NTU	Product NTU	SF	ACF	Tot	Conventional Plant	Savings	% Savings
Case A (RR Turbidity: 95%, Cl: 95%, HME: 99.5%)													
40	2	1.237	19.3815	12	1.4339	25	2	13194	13333	92854	93900	1046	1.11
Case B (RR Turbidity: 97%, Cl: 97%, HME: 99.5%)													
40	2	2.04	18.980	12	1.4190	25	2	12639	12917	90912	93900	2988	3.18
Case C (RR Turbidity: 99%, Cl: 97%, HME : 99.5%)													
40	2	2.82	18.590	12	1.4044	25	2	12361	12500	89522	93900	4378	4.66
Case D (RR Turbidity : 99%, Cl : 97%, HME : 99.5% with bypass 20m3 to break tank)													
40	2	5.25	17.375	12	1.3577	13.5	2	11945	12083	88056	93900	5844	6.22
Case D1 (RR Turbidity : 99%, Cl : 97%, HME : 99.5% with bypass 25m3 to break tank)													
40	2	5.85	17.075	12	1.3459	12.22	2	11667	11700	86734	93900	7166	7.63
Case D2 (RR Turbidity : 99%, Cl : 97%, HME : 99.5% with bypass 27m3 to break tank)													
40	2	6.05	16.975	12	1.3420	11.79	2	11600	11650	86500	93900	7400	7.88
Heavy Metal Ion Exchanger													
40	2	0.157	19.922	17	1.2398	90	0.45	19900		20000			

Table 4.4 : Simulation of Optimized Wastewater Treatment System

From the simulation, it is noticed that the bypass on the Heavy Metal Ion Exchanger does not provide any significance to the capital costs of the system. Hence, the bypass of the Heavy Metal Ion Exchanger is eliminated. From Table 4.4, it is noticed that the higher the removal ratio of the unit operation, the more savings could be done on the system by increasing the bypass flowrate. This is because the higher the removal ratio, the better quality of the effluent that could be produced. Hence, higher flowrate of decentralized stream could be introduced for cost savings.

In order to further increase the possible savings of the system, a recycle stream is introduced to recycle certain portion of the treated water back into the break tank. This step could be able to significantly reduce the concentration of the contaminant in the incoming wastewater. Hence, increasing the bypass stream of each unit operations and decreasing the size of the unit operations. This alternative would not require any additional costs since in every treatment system there will be an emergency bypass stream that will lead the effluent back to the break tank if the parameter of the treated effluent does not comply with the standard value. Certain modification need to be done in order to utilize the emergency bypass stream. However, no extra capital cost is needed in this optimization design. Alternatives D, D1 and D2 are having the same removal ratio of all the component of the system but vary in the bypass flowrate. This is done in order to determine the optimum saving value for the system.

From the simulation, it is noticed that the alternative D2 provide the highest savings of the vessel costs. However, alternative D is favoured due to the bypass volume of the effluent to the break tank. It is not preferable to recycle too much treated water to the break tank to avoid over-loading of the system. (Increasing operation time)

4.3. Recycle Stream

The implementation of the recycle system must be accompanied by PLC (Programmable Logic Controller). PLC is one of the most commonly used controllers in current industries. It serves as a core controller of the plant function. The PLC will adjust the recycle rate of the treated effluent to the break tank proportionate to the level of the equalization tank via level sensor. The recycle system would only being used during non-peak operation hours, where the incoming wastewater level of the equalization tank is not more than the medium level. This is because the influent is produced at maximum rate; recycle of treated effluent at high level will result in overflow at the equalization sump. Besides, the constant recycle of the treated effluent would increase the operation time and hence the operation costs of the wastewater treatment plant. However, it could be avoided by conducting operating costs including the maintenance costs versus capital cost savings engineering economics analysis.

By implementing the recycle system, the concentration of the influent contaminants is decrease. This would allow more influent flowrate to be bypassed in the decentralized stream of pre-treatment units. It will also increase the lifetime of operation for each unit operations per **backwash or regeneration**. Backwash and regeneration are one of the major contributors to the operation costs. The implementation of recycle stream during non-peak operation hours could also reduce the operating costs of the wastewater treatment plant.

4.4 Significance of the Wastewater Treatment System

The major advantage of the system is not only of its cost saving characteristics, but also its flexibility in operation. It could serve as both new project proposals for clients and also for future expansion of existing wastewater treatment plant.

4.5 Other Considerations

The optimized treatment system reduces the operation costs of the system. This is discussed at section 4.3 on the system's ability to adjust its operation loading with respect to influent volume. The designed system and sizing of its unit operations is based on the maximum operating condition of the treatment system without recycle stream. During medium and low level flowrate, the plant operates with the final recycle stream because the incoming feed wastewater flowrate is low.

Other consideration such as the piping costs, the operation cost and the space constraints is also being discussed. The costs of constructing the extra bypass piping could be neglected due to its small amount relative to the savings on the unit operations. For example, the final recycle stream does not required any further costs as it is modified from the conventional emergency bypass stream. The operation costs and maintenance costs of the plant are not the main criteria of the study as per the problem statement. However, the implementation of the new system should not increase any extra costs significantly but it may help in the system's cost savings. The space constraints of the plant should not pose any problem since the system only involved further modification of piping system that would not take up more spaces. However, it could be a major obstacle if future expansions of the system need to be made.

CHAPTER 5

CONCLUSION

The optimization of Industrial Heavy Metal Wastewater Treatment Plant was simulated using Microsoft Excel Spreadsheet. From the process sensitivity analysis, it is found that the capital cost of the system could be decrease by implementing the decentralized system. The effluent quality stated in the Environment Quality Act 1974 under Environmental Quality (Sewage and Industrial Effluents) Regulations 1979 sets the degree of the decentralization allowed. The system being studied could provide a flexible degree to cope with the quantity and quality changes of the influent wastewater by manipulating the split and bypass amount of each unit operations. The main method that being implemented in reducing the capital costs of the system is by bypassing a certain amount of wastewater but maintaining a safe effluent discharge quality. The generalized results could be adapted to different systems and industries. For future continuation of this project, it is proposed that there could be an increase of number of treatment unit and also the consideration of other factors such as operation costs and maintenance costs.

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Internet Website:

Bayer Chemical. < http://www.ionexchange.com/ion/en/index.asp

APPENDIX

Appendix 1 : Specification of Heavy Metal Wastewater Treatment Plant and Environmental Quality (Sewage and Industrial Effluent) 1979, Standard B

1. Design Capacity
   40 m^3/hr Industrial Wastewater Treatment Plant

2. Design Factor
   20% safety factor

3. Combined Rinse Waste Characteristics
   pH : 1.0- 2.5
   BOD_5 : < 2 mg/l
   COD : < 10 mg/l
   SS : < 30 mg/l
   Mercury : < 0.001mg/l
   Cadmium : < 0.03 mg/l
   Copper : < 90.0 mg/l
   Cyanide : < 0.05 mg/l
   Lead : < 1.62 mg/l
   Chromium, Trivalent : < 0.01 mg/l
   Manganese : < 0.02 mg/l
   Nickel : < 35.0 mg/l
   Tin : < 3.60 mg/l
   Zinc : < 1.75 mg/l
   Boron : < 0.40 mg/l
   Fe : < 0.56 mg/l
   Phenol : < 0.07 mg/l
   Free Chlorine : < 0.10 mg/l
   Sulfide : < 0.01 mg/l

4. Acid/Alkali Concentrated Waste Characteristics

pH : 0.5 – 1.0
BOD_5 : < 21 mg/l
COD : < 449 mg/l
SS : < 2080 mg/l
Mercury : < 0.015 mg/l
Cadmium : < 1.25 mg/l
Copper : < 5020 mg/l
Cyanide : < 0.05 mg/l
Lead : < 17.3 mg/l
Chromium, Trivalent : < 0.9 mg/l
Manganese : < 0.65 mg/l
Nickel : < 2110 mg/l
Tin : < 12.9 mg/l
Zinc : < 88.4 mg/l
Boron : < 0.2 mg/l
Fe : < 46.5 mg/l
Phenol : < 0.02 mg/l
Free Chlorine : < 0.1 mg/l

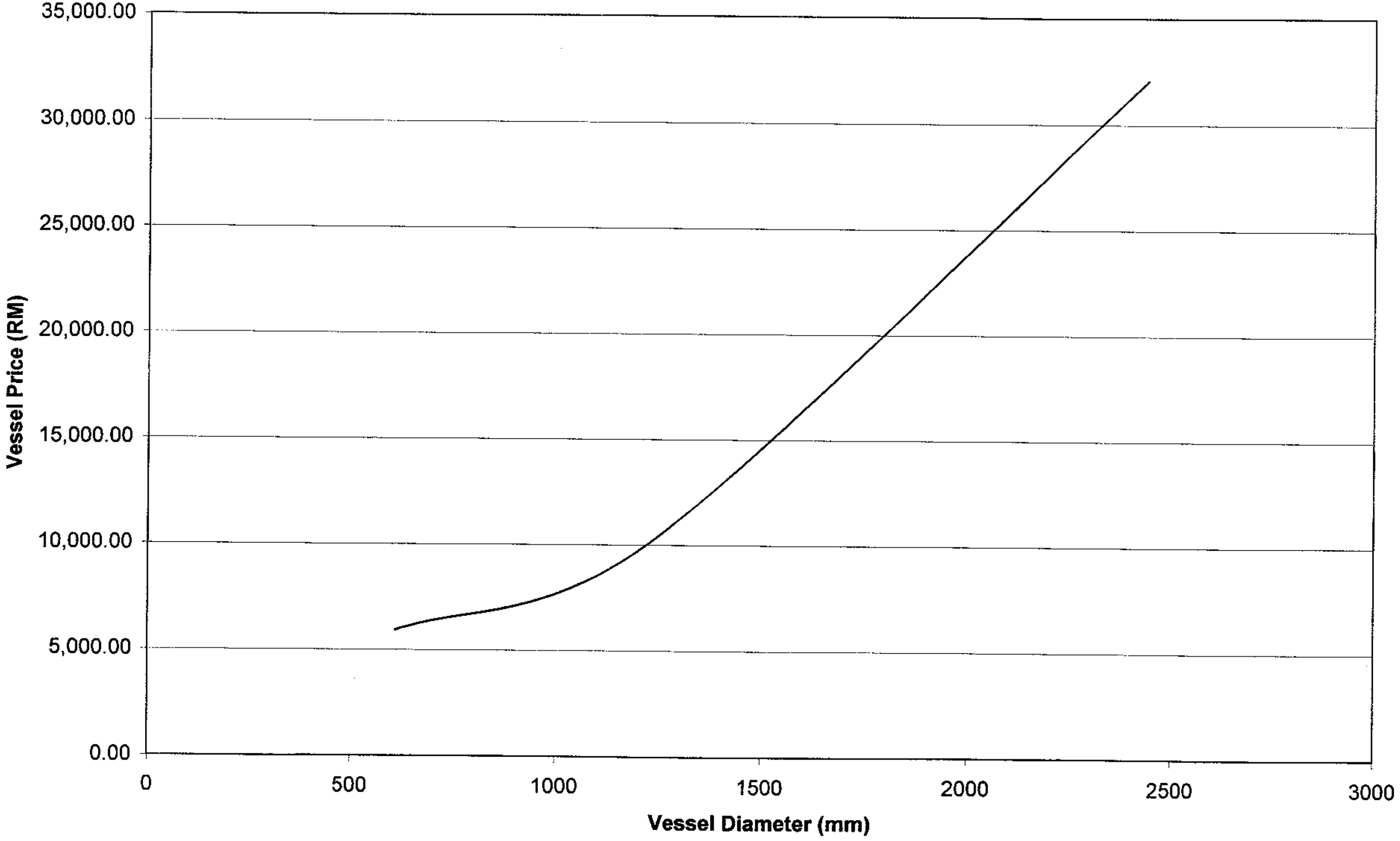
5. Wastewater Discharge Specification (Standard B)

pH : 5.5 - 9.0
BOD_5 : < 50 mg/l
COD : < 100 mg/l
SS : < 100 mg/l
Mercury : < 0.05 mg/l
Cadmium : < 0.02 mg/l
Copper : < 1 mg/l
Arsenic : < 0.1 mg/l
Cyanide : < 0.1 mg/l
Lead : < 0.5 mg/l
Chromium, Trivalent : < 1.0 mg/l
Manganese : < 1.0 mg/l
Nickel : < 1.0 mg/l
Tin : < 1.0 mg/l
Zinc : < 2.0 mg/l
Boron : < 4.0 mg/l
Fe : < 5.0 mg/l
Phenol : < 1.0 mg/l
Free Chlorine : < 2.0 mg/l
Sulfide : < 0.5 mg/l
Oil & Grease : < 10 mg/l

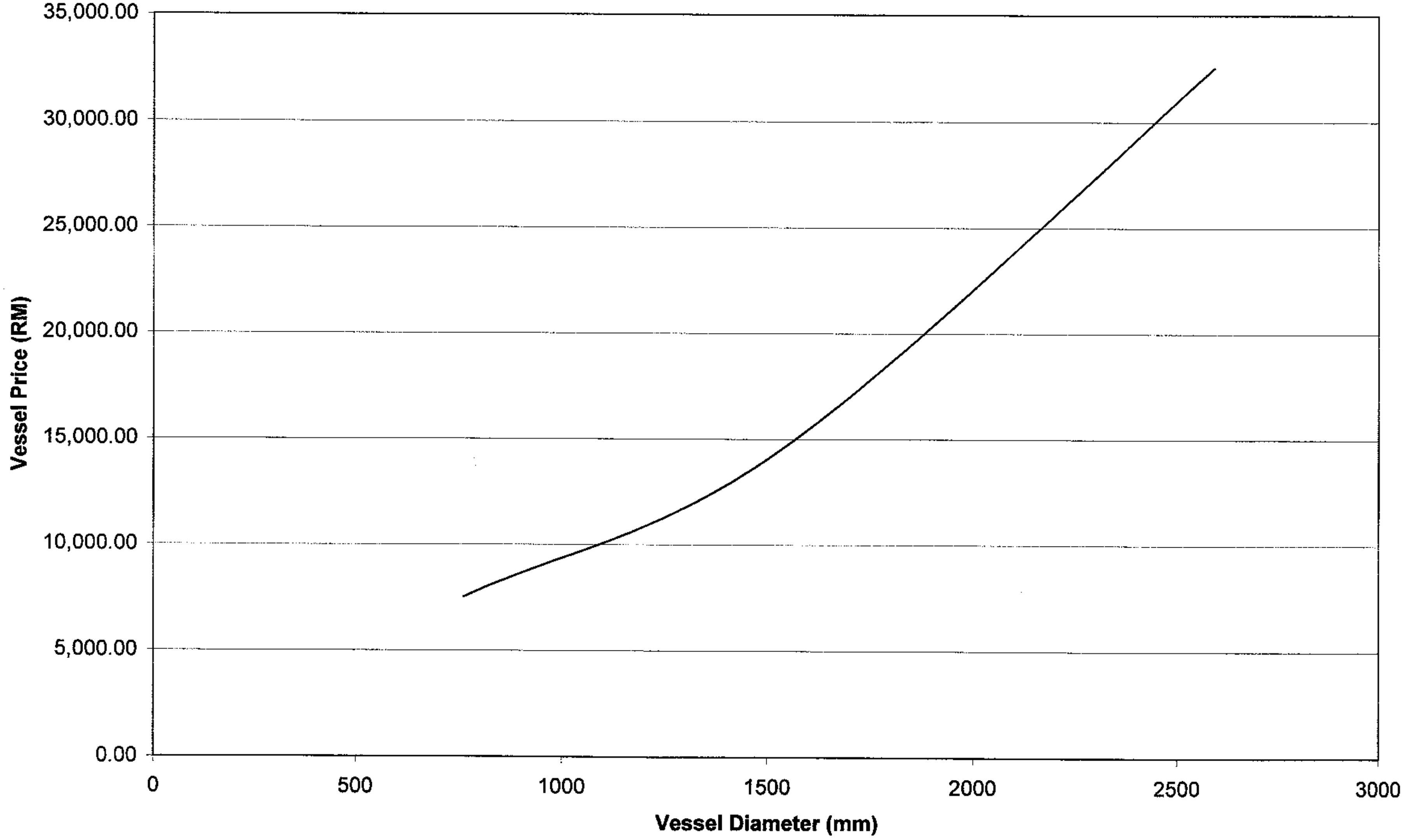
Appendix 2 : Specification of Ion Exchange Resins and Sizing

Waste Water Plants (End of pipe)		**Basic Design**			
Project		US Filter, Malaysia			
		24.8.2001		**7.5.2002**	
Input values :		email Chong 24.8.		**email Chong 7.5.**	
Resin type : Lewatit...		TP 207		TP 207	
Feed volume		30.00	m³/h	30.00	m³/h
Temperature			°C		°C
pH		4.00		4.00	
Feed composition :					
Cu		97.90	ppm	97.90	ppm
Ni		31.80	ppm	31.80	ppm
Pb		1.62	ppm	1.62	ppm
Sn		3.60	ppm	3.60	ppm
As		0.50		0.50	
Total		135	ppm	135	ppm
Customers specification purified water :					
Cu		1.0	ppm	1.0	ppm
Ni		1.0	ppm	1.0	ppm
Pb		0.5	ppm	0.5	ppm
Sn		1.0	ppm	1.0	ppm
As		0.1	ppm	0.1	ppm
Our recommendation :					
Arrangement : 2 columns in series					
Resin volume per column, after conditioning (Na-form)		2	m³	**3.6**	m³
Inert resin volume per column				**0.8**	m³
Vessel diameter,outer		[illegible]	mm	**1544**	mm
Vessel diameter,internal		[illegible]	mm	**1524**	mm
Freeboard		[illegible]	%	**0**	%
Expected operating capacity, related to Na-form		[illegible]	g/l	**54.0**	g/l
Calculated values :					
Specific Flow Rate, related to Na-form		1[illegible].0	BV/h	**8.3**	BV/h
Vessel cross section		1.[illegible]4	m²	1.824	m²
Bed depth of TP 207		1.[illegible]96	m	**1.974**	m
Bed depth of inert resin IN 42				**0.439**	m
Freeboard		[illegible]96	m	**0.000**	m
Vessel cylindric height		2.[illegible]93	m	**2.412**	m
Linear velocity		1[illegible]5	m/h	16.45	m/h
Pressure loss		[illegible]	kPa	35.7	kPa
Pressure loss		[illegible]	bar	0.36	bar
Expected throughput, related to Na-form		[illegible]2	BV	399	BV
		[illegible]5	m³	1436	m³
Expected running time		22	h	**48**	h

Activated Carbon Filter Vessel Pricing Chart



Sand Filter Vessel Pricing Chart



Ion Exchange Vessel Pricing Chart