Energy Audit of Sewage Treatment Plants

By

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Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(Ir. Dr. Mohd Shiraz Bin Aris)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
August 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.

Ashraf Aizzuddin b. Abd. Rahni

ABSTRACT

The objective of this study is to conduct an energy audit of a sewage treatment plant, analyze the energy consumption and efficiency of the STP and design energy conservation measures to reduce energy consumption and cost. It also serves as a continuation and monitoring of Pantai Dalam STP's previous energy audit 2008-2010. At national level, IWK's total operating cost has increased at a much higher rate than its total revenue. In 2009, the company's loss amounts to RM33 million. From that total, the energy cost contributes about 19%. At branch level, for 2008-2010, Pantai Dalam STP's energy cost contributes about 56% which is much higher. This shows that energy has become one of the main contributors for their high cost, thus solutions should be identified to optimize their energy efficiency and minimize the cost. The scope of study is conducting an energy audit to analyze the energy usage of the plant. The methodologies for the energy audit are the pre-site work: plant and utility data analysis, site visit: walk-through survey and post-site work which comprises of baseline for building energy use and evaluation of energy savings measures. Finally, the findings indentifies that the largest energy user is the sewage lift pumps at the pump station, followed by the blowers, clarifiers and aeration tank. It also identifies that the previous energy audit still has not achieved its goal of a 10% reduction but already half-way there. Thus, further initiatives and monitoring is required in achieving it. The sewage lift pump is also identified to be inefficient and has a potential maximum savings of **34,815 kWh/month** or **RM8,024.86/month**. Energy savings measures to achieve this is changing the speed to 90%, which will increase its efficiency to 80.5% and yield a saving of **31,371 kWh/month** or **RM7,231.02/month.** Others include installing new properly sized pumps, changing the pump impellers and replacing the motor.

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ABBREVIATIONS AND NOMENCLATURES

BEP	Best efficiency point
EPRI	Electric Power Research Institue
IWK	Indah Water Konsortium Sdn. Bhd.
SAIC	Science Applications International Corporation
SS	Suspended solids
STP	Sewage treatment plant
TNB	Tenaga Nasional Berhad

CHAPTER 1

INTRODUCTION

1. BACKGROUND

According to Malaysia Green Technology Corporation (2010), one of the National Energy Policies is to promote the efficient utilization of energy and to discourage wasteful and non-productive patterns of energy consumption [1]. Thus, energy efficiency is an important component as the world moves towards green technology and becoming more efficient. Energy, which also equals to cost, is growing rapidly in demand to cater the rising population and development. According to the Energy Commission report, for the first half of 2010 the industrial sector comprises the largest segment (44%) of TNB's energy sales [2]. Thus, the need to monitor and manage the energy usage is important, especially in the industrial sector. An objective and effective method to achieve this is by doing an energy audit. In this study, the industry is scaled down to a sewage treatment plant, and the chosen STP is Indah Water Konsortium Sdn. Bhd. Pantai Dalam branch.

2. PROBLEM STATEMENT

According to IWK Sustainability Report (2008-2009), at national level IWK's total operating cost has increased at a much higher rate than its total revenue [3]. It had exceeded the revenue, resulting in unsustainability. From 1998 to 2009, it has increased by 634% while the revenue increased by only 155%.[1] In the end, the company's loss amounts to RM33 million. From that total, the energy cost contributes about 19%. At branch level, according to Pantai Dalam STP's previous energy audit 2008-2010 the energy cost contribution is much higher which is 56% [4].[2] This is primarily due to the increase in number of STPs and electricity tariff rate, which is estimated to be the mean High Voltage Peak/Off-Peak Industrial Tariff rate of RM0.2305/kWh for IWK. This clearly shows that energy has become one of the

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[1] Refer appendix 1.1

[2] Refer appendix 1.2

main contributors for the high cost, thus a solution should be designed to optimize its efficiency and minimize its cost.

3. OBJECTIVES AND SCOPE OF STUDY

The objective of this project is to conduct an energy audit of a sewage treatment plant, specifically the Pantai Dalam STP. The energy audit will analyze the energy consumption and efficiency. It also serves as a continuation and monitoring of the Pantai Dalam STP's previous energy audit 2008-2010. Finally, energy conservation measures will be identified to reduce energy consumption and cost. The scope of study is conducting an energy audit to analyze the energy usage of the plant.

CHAPTER 2

LITERATURE REVIEW

1. ENERGY AUDIT

According to Malaysia Green Technology Corporation, "Energy audits are a systematic study or survey to identify how energy is being used in a building or a plant. It is also a useful procedure to find out the best options for energy conservation. Energy audits provide an analysis of the amount of energy consumed during a given period in the form of electricity, gas, fuel, oil or steam. Using that information, it is also possible to list how the energy was used according to the various processes in a plant or at the various outlets in a building. The next step in an energy audit then is to identify the potential for energy savings accurately".

According to Albert and William (2008), energy audit is defined as a process to evaluate where a building or plant uses energy, and identify opportunities to reduce consumption [5]. They also state that they are many types of energy audits. The most common ones are:

a) Level 1: Walk-through or preliminary audit
   The simplest and quickest type of audit which involves minimal interviews with site operating personnel, a brief review of facility utility bills and other operating data, and a short on-site visit to identify area where simple and inexpensive energy conservation measures can be taken. Basically, only major problem areas will be uncovered. Corrective measures are briefly described and quick estimates of implementation cost, potential operating cost savings, and simple payback periods are provided. Includes an evaluation of energy consumption data to analyze energy use patterns and provide comparisons to industry benchmarks for similar facilities.

b) Level 2: Standard or general audit

A comprehensive energy analysis that expands on the preliminary audit described above by collecting more detailed information about facility operation and performing a more detailed evaluation of energy conservation measures identified. Utility bills are collected for a 12 to 36 month period to allow the auditor to evaluate the facility's energy/demand rate structures, and energy usage profiles. Additional metering of specific energy-consuming systems is often performed to supplement utility data and to quantify energy use and efficiency of various systems. In-depth interviews with facility operating personnel are conducted to provide a better understanding of major energy consuming systems as well as insight into variations in daily and annual energy consumption and demand. It also includes the development of a baseline for energy use and evaluation of energy savings and cost effectiveness of appropriate energy conservation measures.

c) Level 3: Detailed or investment-grade audit

The most comprehensive and time consuming audit that expands on the general audit described above by providing a dynamic model of energy use characteristics of both the existing facility and all energy conservation measures identified. It includes the use of instruments to measure energy use, sophisticated computer simulation programs and more rigorous economical evaluation of energy conservation measures

2. SEWAGE TREATMENT PLANT

According to IWK (2011), their sewage treatment methods consist of [6]:

1. Physical unit operation: use applications of physical forces e.g. screening
2. Chemical unit process: involves addition of chemicals or by chemical reactions e.g. disinfection
3. Biological unit processes: involves biological activity e.g. oxidation pond

Figure 2.1 below shows the general sewage treatment flow in an STP.

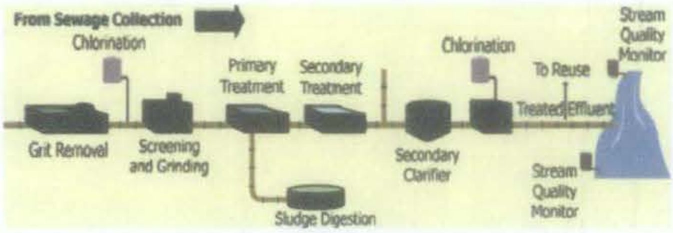


Figure 2.1 Typical IWK sewerage treatment plant

Figure 2.2 below shows the Science Applications International Corporation (2006) study results for energy consumptions average of activated sludge wastewater treatment plant [7].

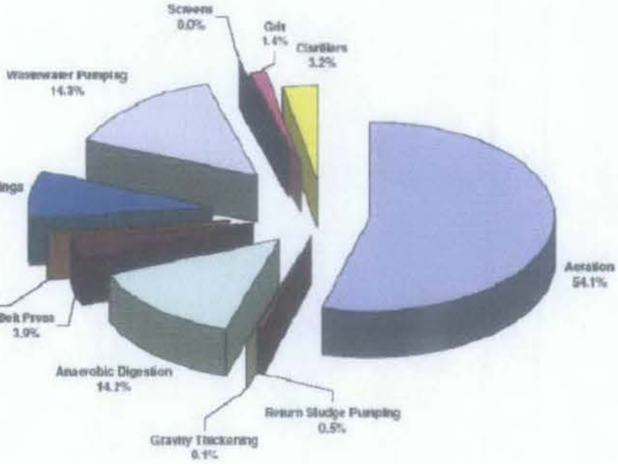


Figure 2.2 Electricity requirements for activated sludge wastewater

This is used as an industry benchmark for identifying large energy users. From the figure, the largest energy consumer is aeration. Pumping and anaerobic digestion should also be given emphasis. Thus, these are the areas that will be targeted and focused in the audit. For the pumps, Electric Power Research Institue (1998) points out that a pump testing can be done by referring the manufacturer's performance curve to determine its operating point [8]. The flow or differential head across the pump (the pressure readings at the inlet and outlet) is measured. For a pump, its selection is important to avoid overdesigning or causing excessive flow. The ideal pump design is to allow efficient operation at average flow conditions.

CHAPTER 3
METHODOLOGY

1. Project Activities

For this project, a standard energy audit will be performed. The specific activities for each procedures of the energy audit are listed below.

1) Pre-Site Work: Plant and Utility Data Analysis
    - Obtain and review drawings and layouts.
    - Collect 1 year of utility data to identify historical energy use pattern.

2) Site Visit: Walk-Through Survey
    - Collect energy consumption data of major energy use equipment.
    - The method used is recording the meter panel readings.
    - 5 readings at an interval of 1 hour each will be taken.
    - The pressure readings of the sewage lift pumps will also be taken from the pressure gauges using the same steps.

3) Post-Site Work:
    i) Baseline for Plant Energy Use
    - Develop an energy use distribution.
    - Develop a baseline model for plant energy use.

    ii) Evaluation of Energy Savings Measures
    - Evaluate the energy use pattern, distribution and cause of energy loss.
    - Evaluate the cost-effectiveness of energy conservation measures using an economical analysis method.

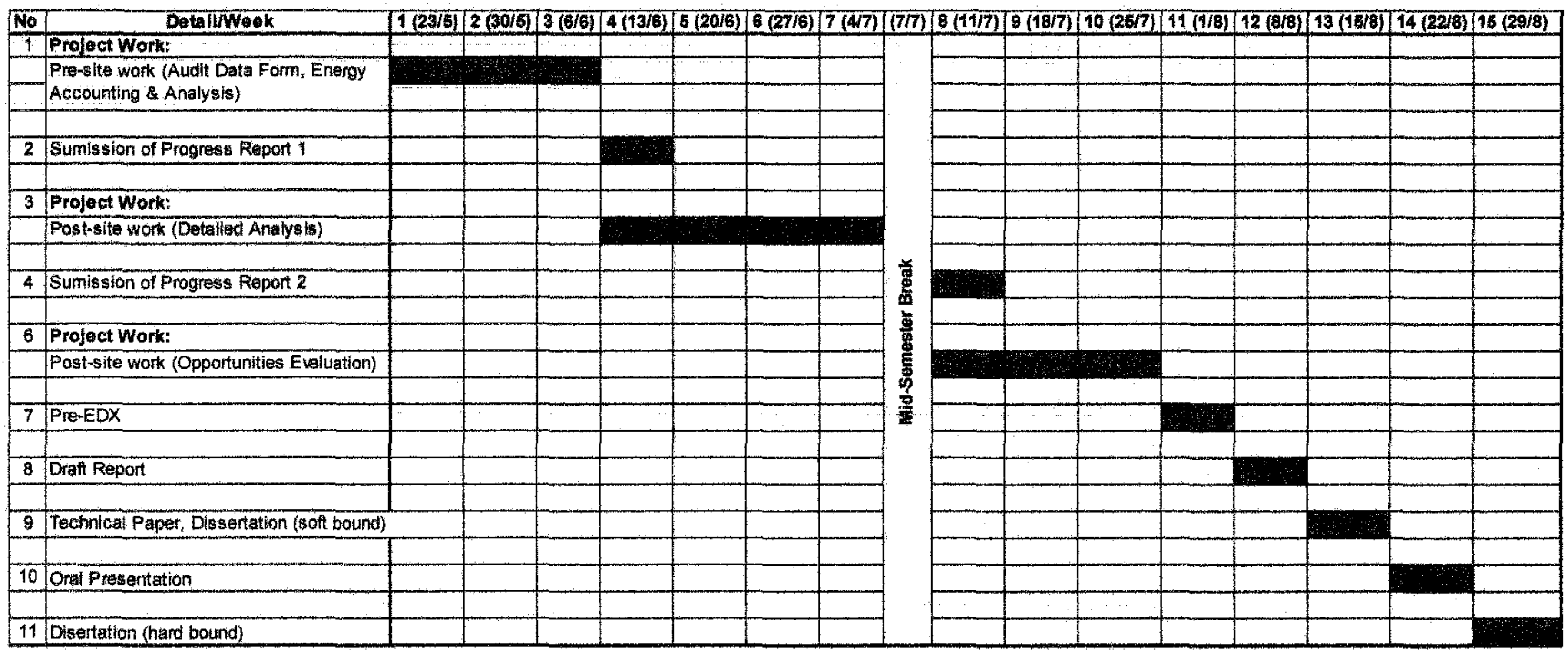
2. Key Milestones

Figure 3.1 below shows the key milestones for FYP I.

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13
1	Selection of Project Topic	■	■					Mid-Semester Break							
2	Preliminary Research Work		■	■	■										
3	Submission of Preliminary Report				■										
4	**Project Work:**														
	Walk-through Audit (UTP STP)					■	■								
5	Sumission of Progress Report								■						
6	Seminar								■						
7	**Project Work:**														
	Standard Energy Audit (IWK STP)														
	Building and Utility Data Analysis									■					
	Walk-through Survey									■					
	Baseline for Building Energy Use									■	■	■	■	■	■
8	Submission of Interim Report Final Draft														■
9	Oral Presentation								During study week						

Figure 3.1 FYP I Gantt chart

Figure 3.2 below shows the key milestones for FYP II.



No	Detail/Week	1 (23/5)	2 (30/5)	3 (6/6)	4 (13/6)	5 (20/6)	6 (27/6)	7 (4/7)	(7/7)	8 (11/7)	9 (18/7)	10 (25/7)	11 (1/8)	12 (8/8)	13 (15/8)	14 (22/8)	15 (29/8)
1	**Project Work:**								Mid-Semester Break								
	Pre-site work (Audit Data Form, Energy Accounting & Analysis)	■	■	■													
2	Sumission of Progress Report 1				■												
3	**Project Work:**																
	Post-site work (Detailed Analysis)				■	■	■	■									
4	Sumission of Progress Report 2									■							
6	**Project Work:**																
	Post-site work (Opportunities Evaluation)									■	■	■					
7	Pre-EDX												■				
8	Draft Report													■			
9	Technical Paper, Dissertation (soft bound)														■		
10	Oral Presentation															■	
11	Disertation (hard bound)																■

Figure 3.2 FYP II Gantt chart

CHAPTER 4
RESULTS AND DISCUSSION

1. Plant and Utility Data Analysis

1.1 Plant Analysis

Figure 4.1 below shows the location of the STP which is situated at the Pantai Dalam district in Kuala Lumpur.

Figure 4.1 Map location

According to the staffs, the Pantai Dalam STP covers most of the areas in Kuala Lumpur. Bernama reported that in 2010 it had undergone a capacity upgrading process to handle sewerage treatment for a population of 1.8 million people from just approximately 900,000 people, nearly double the amount. This is to cater the rapid population increase. The service area sewage which is a series of ponds is collected and conveyed to the Pantai Dalam STP at the opposite side across the highway through the pump station. The effluent is lastly discharged to the Klang River. Figure 4.2 below shows the Pantai Dalam plant overview which comprises of administration buildings and process buildings.

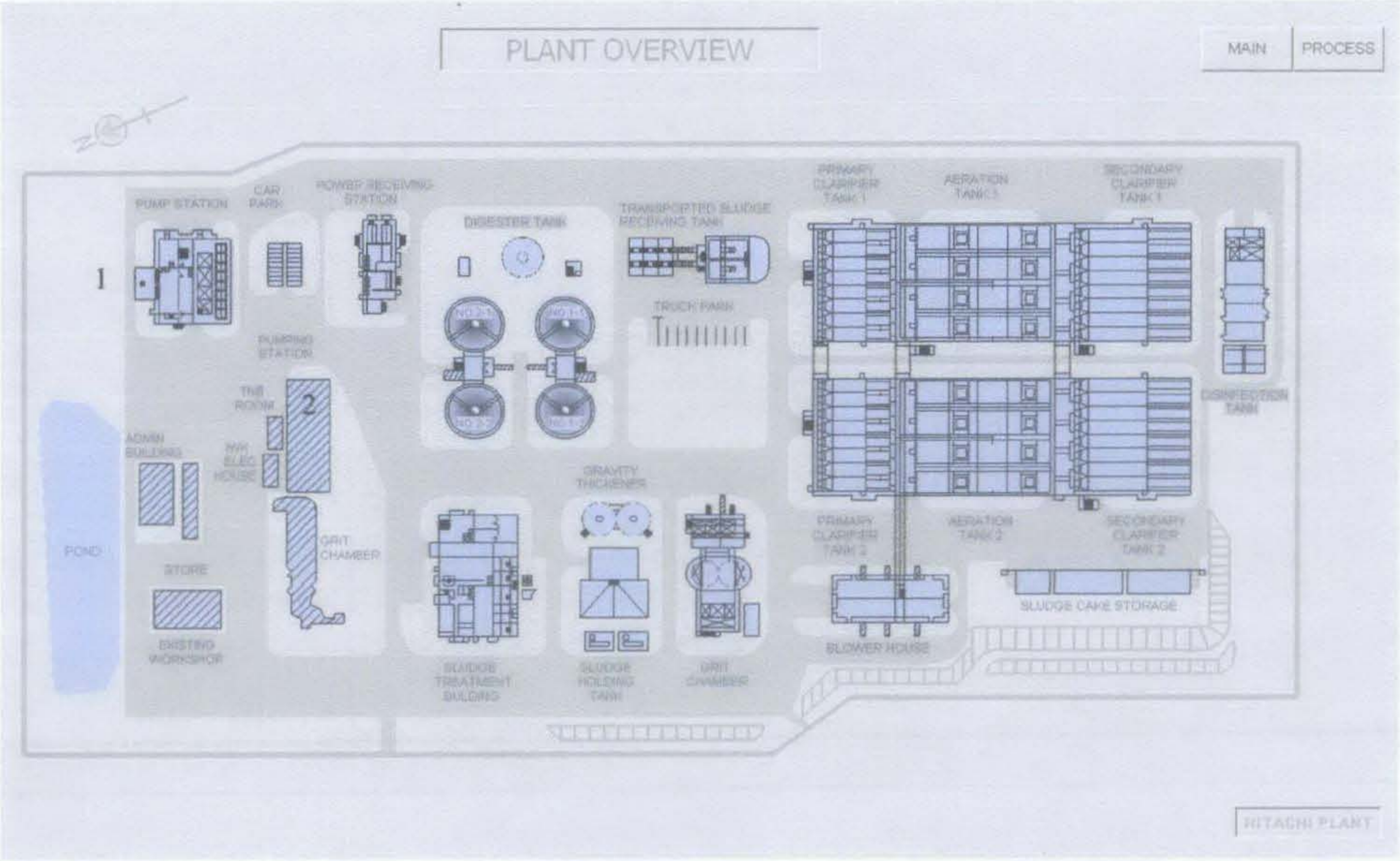


Figure 4.2 Plant overview

Previously it used the pond as an oxidation pond but now it had been replaced with various technologies to ensure a more efficient process. The new pump station (1) replaces the old one (2). The staffs there explained that the peak operation time is at 11.00 a.m. The discharge process is around 9.00 a.m. thus it takes the waste about 2 hours to arrive at the plant. The whole process takes about a total of 12 hours. Figure 4.3 below shows the process overview.

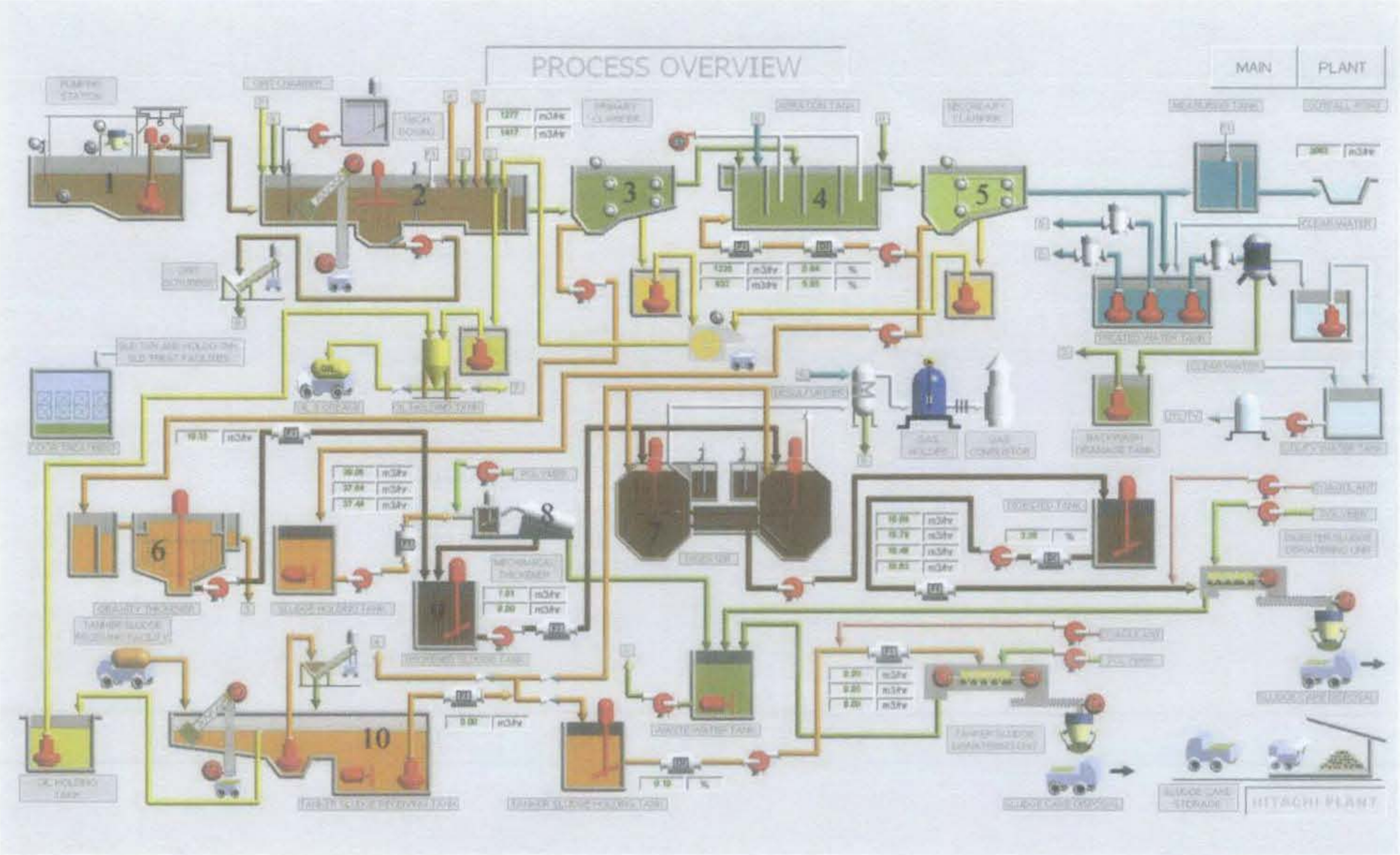


Figure 4.3 Process overview

The first main process is the pump station (1) where sewage enters here from 2800 mm diameter of trunk sewer and it is stored and transferred to the distribution well before it flows to the grit chamber (2) and existing plant by the lift pumps. The role of the grit chamber is to remove grit contained in sewage to avoid damaging subsequent process equipment.

Then it flows to the primary clarifiers (3) which clarifier and remove small, light particles, suspended solids (SS) and biochemical oxygen demand (BOD) from sewage which passes through while maintaining horizontal velocities below the scouring velocity and to reduce treatment load from subsequent biological treatment facilities.

Next is the aeration tank (4) which has staged aeration process is to remove BOD, SS and nitrogen is employed. The mixed liquor from the aeration tank then enters the secondary clarifier (5) which clarifies the activated sludge and the treated water. The gravity thickener (6) utilizes gravity force to separate water from sludge. Next is the digester (7) which purpose is to further stabilize the thickened sludge coming from the mechanical thickener (8) and gravity thickener which is stored in thickened sludge holding tank (9) in anaerobic condition. Finally is the tanker sludge facility (10) which receives tanker sludge from domestic desludging.

1.2 Utility Data Analysis

Table 4.1 below shows the Pantai Dalam STP utility data for 1 year.

Table 4.1 Utility data

Month	Inflow (m^3)	Energy consumption (kWh)	Electricity cost (RM)
Jan '10	1,813,330	1,294,982.40	385,616.88
Feb '10	1,671,520	1,181,061.28	367,540.49
Mar '10	1,945,250	1,348,293.44	387,242.89
Apr '10	1,792,460	1,324,927.15	379,443.40
May '10	1,724,300	1,311,279.97	378,016.15
Jun '10	1,944,930	1,228,972.56	379,322.22
Jul '10	2,484,630	1,550,517.70	379,321.40
Aug '10	2,188,640	1,542,878.37	445,626.80
Mar '11	2,306,400	1,600,232.09	328,068.70
Apr '11	2,146,750	1,589,231.10	399,132.30
May '11	1,918,730	1,224,368.56	396,088.80
Jun '11	2,153,750	1,334,512.80	365,484.00
Average	**2,007,558**	**1,377,604.79**	**382,575.34**
Total	**24,090,690**	**16,531,257.42**	**4,590,904.03**

Four months of energy consumption data (September '10 - February '11) was not available due to SCADA server breakdown. The average flow is about 2 million m^3/month, average energy consumption is about 1.4 GWh/month and electricity cost is about RM380,000/month. The observation that several higher energy consumption yields a lower cost is most probably due to most of its operations are running during off-peak period which results in a lower tariff.

2. Walk-through Survey

Table 4.2 below shows the power consumption data for each facility.

Table 4.2 Power consumption data[3]

Facility	Total average power (kW)	Total energy (kWh/day)
Sewage lift pump	456	10954
Blower	351	8418
Clarifier & aeration tank	130	3120
Grit chamber	5	132
Utility water	18	420
Sludge thickener	32	775
Sludge digestion	15	369
Digested sludge dewatering	28	669
Tanker sludge dewatering	2	49
Total	**1038**	**24905**

---

[3] Refer appendix 4.1 for full data

The highest power consumer is the pump, followed by the blower, clarifier and aeration tank. The values differ from the previous energy audit[4] as the previous one was fully taken with the SENTRON PAC3200 Power Meters (as shown in Figure 4.4 below) and data loggers, thus are actually more accurate. However, they were not available this time, thus an alternative method had to be used. The daily fluctuations and non-continuous readings also caused the differences. However, it can still be used as a reference, and some of the readings were quite similar too such as the grit chamber. The different facility categories are also according to the meter panel labels, while the previous audit used different ones. The meter panels also did not distinguish the clarifier and aeration tank process, thus the combined total for both processes was taken. The blowers are separated even though it is also a part of the aeration process. This actually shows that the blower is the main energy consumer in the process.

Figure 4.4 SENTRON PAC3200 Power Meter

3. Baseline for Plant Energy Use

Figure 4.5 below shows an overall energy baseline for electric energy use and cost per cubic meter of influent treated for the 12 month period.

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[4] Refer to appendix 4.2

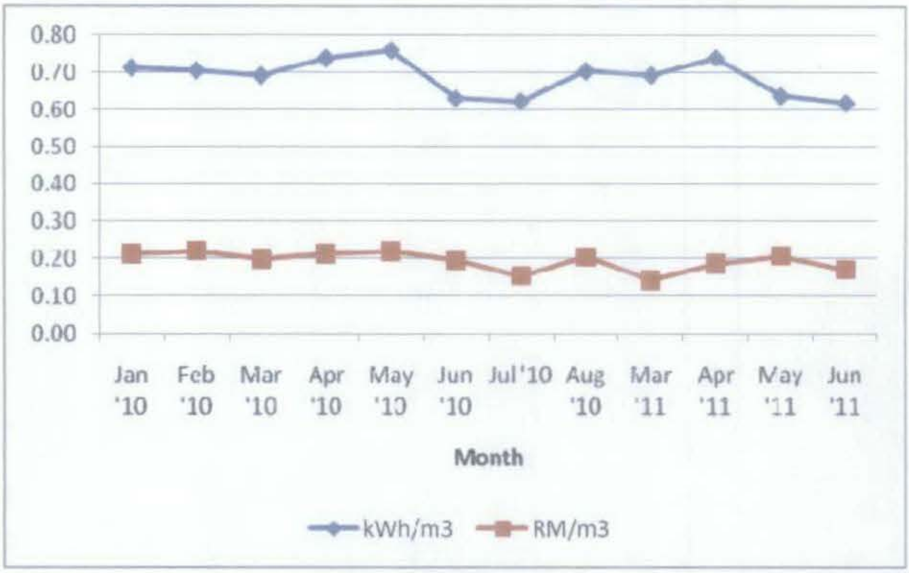

Figure 4.5 Energy consumption and electricity cost per cubic meter of influent

Here the trend is the consumption kWh/m^3 increases in the middle of the year in April '10 then decreases in June '10. It increases again in August '10 and decreases again in May '11. The average energy consumption per cubic meter from August '10 to June '11 is 0.68 kWh/m^3. Comparing this to the previous energy audit[5] which averaged 0.72 kWh/m^3, it is 5.6% lower. Thus the previous goal of a 10% reduction or 0.64 kWh/m^3 was still not fully achieved but already half-way there. Therefore, the need to further monitor and push efforts in achieving it is required. On the other hand, the cost RM/m^3 shows a quite similar fluctuation but in a smaller scale and generally more stable, which is again most probably due to the increase mostly happening during off-peak periods as it did not largely affect the cost. Figure 4.6 below shows the energy use distribution.

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[5] Refer to appendix 4.3

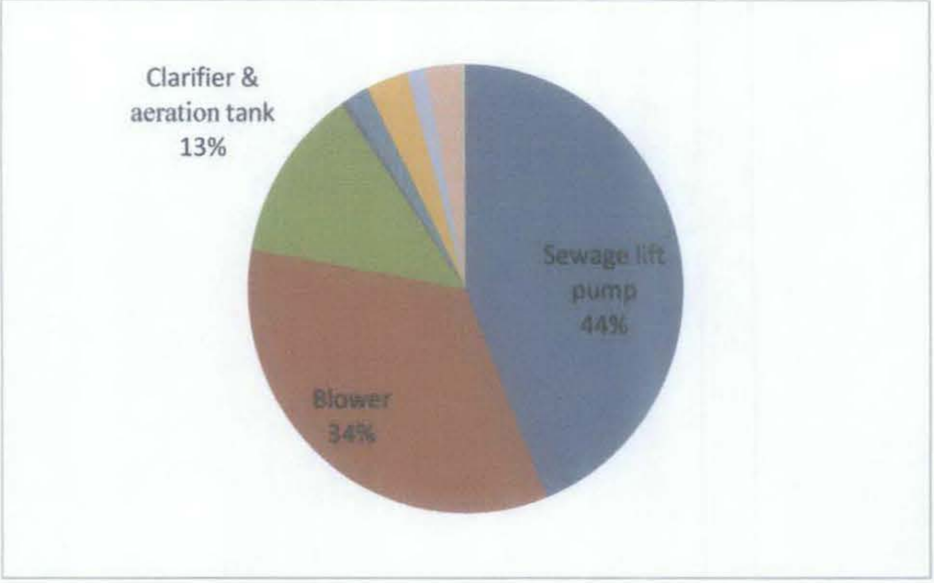

Figure 4.6 Energy use distribution

The highest energy consumer is the sewage lift pump and blower. Although the % is quite different than the SAIC study, it is still quite the same in terms of the major energy consumers. The % is however quite similar and consistent with the previous energy audit[6] results. Thus, it confirms the major energy users of the plant. It also shows that the manual readings are still reliable to be used as a reference.

4. Evaluation of Energy Savings Measures

As the pump is identified as the highest power consumer, it is further evaluated. Figure 4.7 shows the operating points of the pumps on the characteristic curve.

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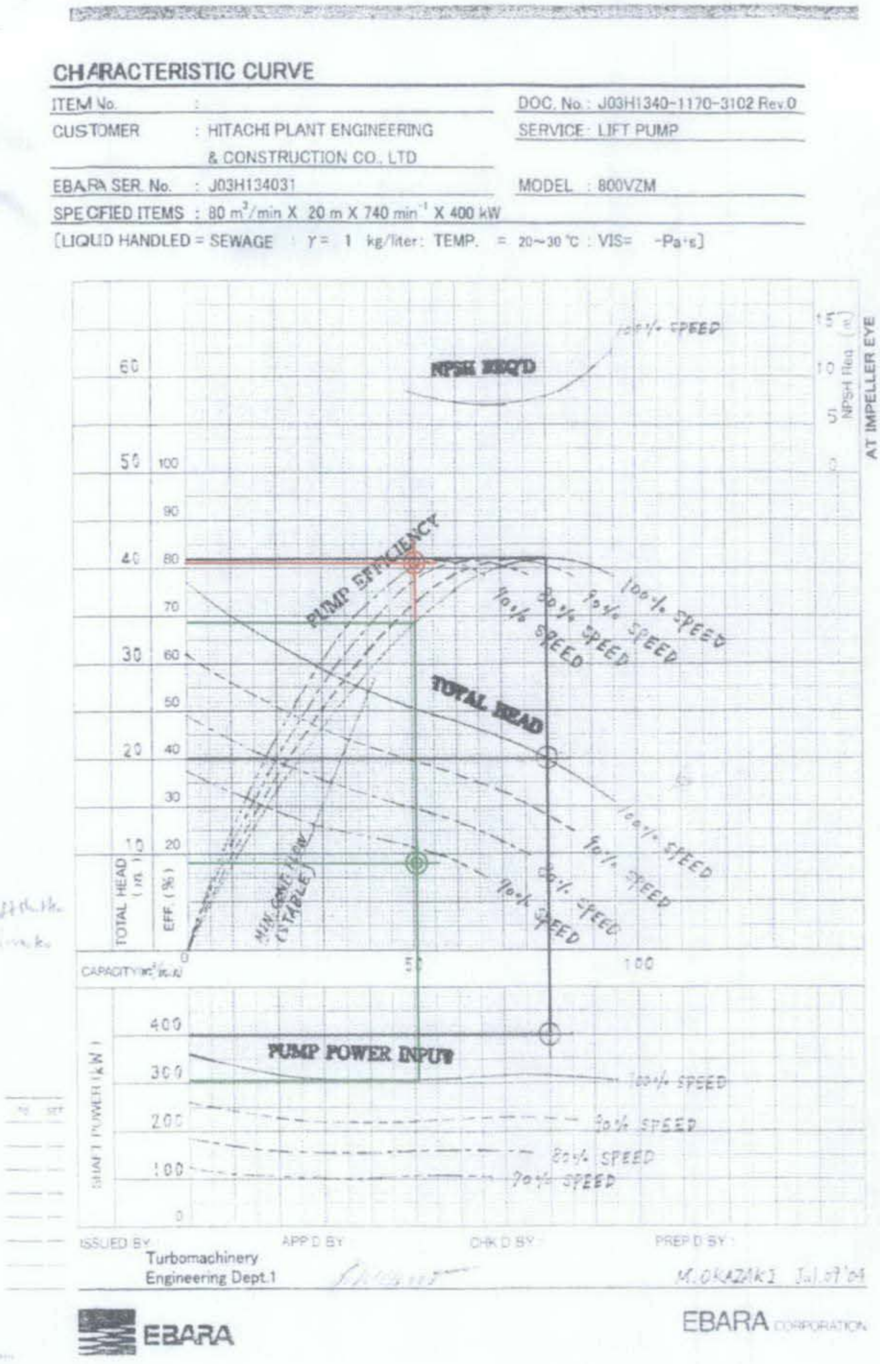
[6] Refer to appendix 4.2



CHARACTERISTIC CURVE

ITEM No. :

DOC. No. : J03H1340-1170-3102 Rev.0

CUSTOMER : HITACHI PLANT ENGINEERING & CONSTRUCTION CO., LTD

SERVICE : LIFT PUMP

EBARA SER. No. : J03H134031

MODEL : 800VZM

SPECIFIED ITEMS : 80 m^3/min X 20 m X 740 min^{-1} X 400 kW

[LIQUID HANDLED = SEWAGE : γ = 1 kg/liter : TEMP. = 20~30 °C : VIS= -Pa·s]

ISSUED BY : Turbomachinery Engineering Dept.1

APP'D BY :

CHK'D BY :

PREP'D BY : M. OKAZAKI Jul.07'04

EBARA

EBARA CORPORATION

⊕	Operating point 1
⊕	Operating point 2
⊕	Best efficiency point

Figure 4.7 Sewage lift pump operating points

From the analysis[7], it is identified that the pumps are only running at 69% efficiency. Thus, it is quite far from the best efficiency point[8] which is 82%. Thus it is identified that the pump has a potential maximum energy savings of **34,815 kWh/month** or **RM8,024.86/month**. Figure 4.8 shows the pumps.

Figure 4.8 Sewage lift pumps

Thus, a method of achieving this is changing the speed to 90%. From the curve, this will achieve a higher efficiency which is 80.5%, close to the optimum efficiency. This will yield a saving of **31,371 kWh/month** or **RM7,231.02/month.** Other energy savings measure, according to the Hydraulic Institute, is by replacing the oversized pumps by installing new properly sized pumps. This will have a higher cost. A lower cost method would be only modifying by trimming or changing the pump impellers to match the output with system requirements when the pumping head exceeds system requirement, which is the case for pump 1. This is as trimming will reduce the impeller tip speed, which will then reduce the energy imparted to the pumped fluid and also lower the head. However the impeller diameter has to be identified first as it is not available. Affinity laws should also be used as the properties for trimmed impellers are not available from the curve. The vendor must also be consulted first to determine the feasibility and minimum impeller diameter for the pump casing. Another measure is replacing the motor with a more energy efficient one.

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[7] Refer appendix 4.4 for calculation

[8] Refer appendix 4.5 for pump specification

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

1. Conclusion

The result indentifies that the largest energy user is the sewage lift pumps at the pump station. This is followed by the blowers, clarifiers and aeration tank. This also concurs with the previous energy audit results. Thus, energy saving measure should focus on those areas.

Besides that, it also identifies that the previous energy audit's goal for a 10% reduction or 0.64 kWh/m^3 was still not fully achieved but already half-way there. Thus, further initiatives and monitoring is required.

Finally, the sewage lift pump analysis identified that it is operating inefficiently. This is the main cause for its energy loss. It is indicated that the pump has a potential maximum energy savings of **34,815 kWh/month** or **RM8,024.86/month**. Energy savings measures to achieve this is changing the speed to 90%, which will increase its efficiency to 80.5% and yield a saving of **31,371 kWh/month** or **RM7,231.02/month.** Others include installing new properly sized pumps, changing the pump impellers and replacing the motor.

2. Recommendations

Future project work recommended is conducting tertiary level audit for further monitoring and analysis. This is to ensure the previous energy audit goal is achieved and for further steps to increase the efficiency of sewage lift pump and other major areas.

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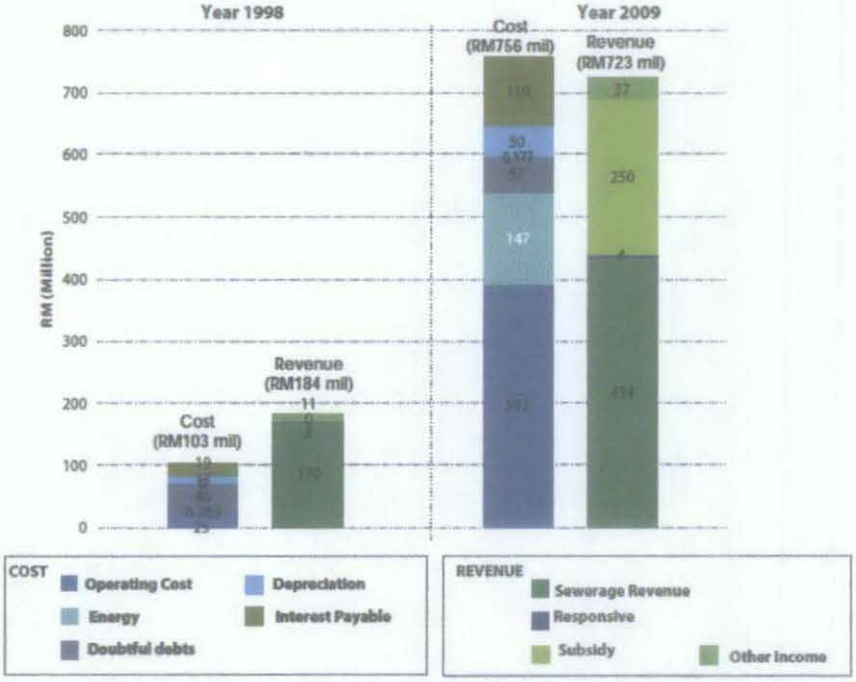
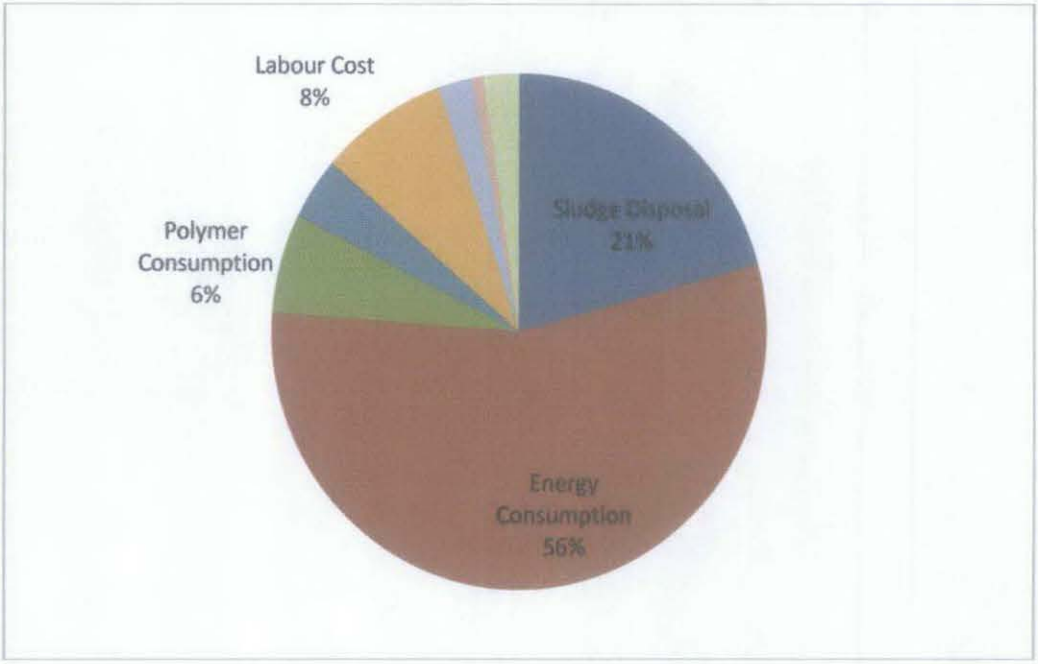
APPENDICES

Appendix 1.1 IWK Revenue and Cost Structure Chart



Appendix 1.2 Previous energy audit: Pantai Dalam major expenses 2008-2010

Data	**RM**
Sludge Disposal	140,400
Energy Consumption	375,000
Polymer Consumption	42,000
Water Consumption	885
Administration Cost	25,932
Labour Cost	56,300
M&E Maintenance/Repairs	15,000
Solid Waste Disposal	5,000
Security	16,000



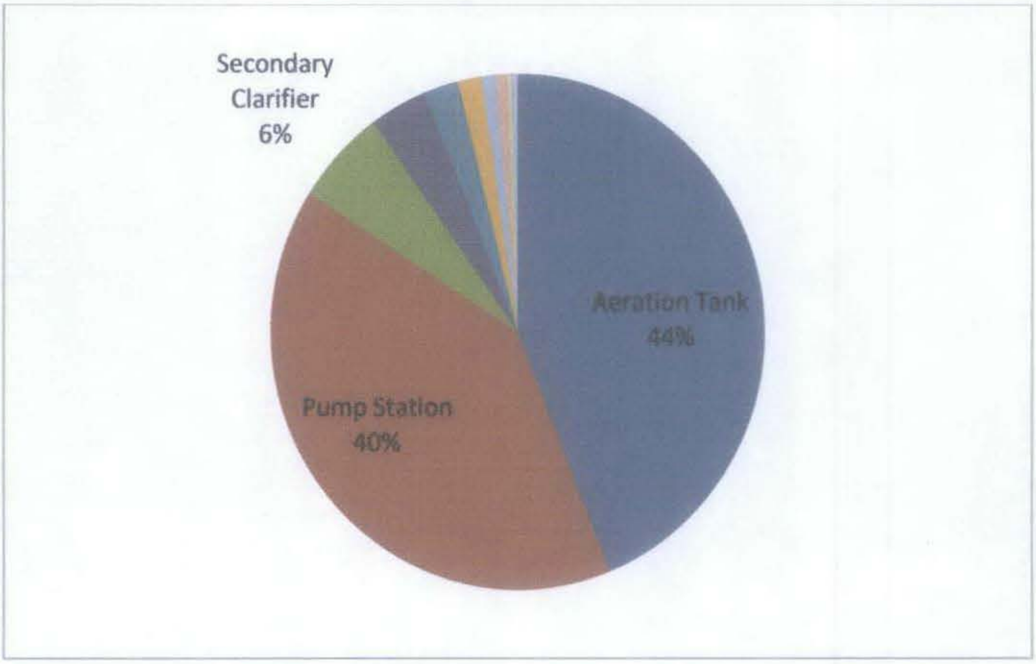
Appendix 4.1 Power consumption data

Facility	**Meter Panel**						**Total average power (kW)**	**Total energy (kWh/day)**
	05/01/2011			**08/08/2011**				
	Current (A)	**Voltage (V)**	**Power (kW)**	**Current (A)**	**Voltage (V)**	**Power (kW)**		
Sewage lift pump								
Pump 1	560	400	224	560	415	232		
Pump 2	560	410	230	560	405	227		
Total power			**454**			**459**	**456**	**10954**
Blower								
Blower 2	280	410	115	278	410	114		
Blower 3	0	0	0	281	410	115		
Blower 5	297	410	122	0	0	0		
Inverter	290	410	119	285	410	117		
Total power			**355**			**346**	**351**	**8418**
Clarifier & Aeration Tank								
Clarifier & Aeration Tank 3	185	240	44	190	240	46		
Clarifier & Aeration Tank 2	50	400	20	195	400	78		
Clarifier & Aeration Tank 4	50	415	21	125	410	51		
Total power			**85**			**175**	**130**	**3120**
Grit chamber	5	410	**2**	22	405	**9**	**5**	**132**
Utility water	30	415	**12**	55	410	**23**	**18**	**420**
Sludge thickener	105	415	**44**	50	420	**21**	**32**	**775**
Sludge digestion	50	410	**21**	25	410	**10**	**15**	**369**
Digested sludge dewatering	100	445	**45**	25	450	**11**	**28**	**669**
Tanker sludge dewatering	5	410	**2**	5	410	**2**	**2**	**49**
						Grand total	**1038**	**24905**

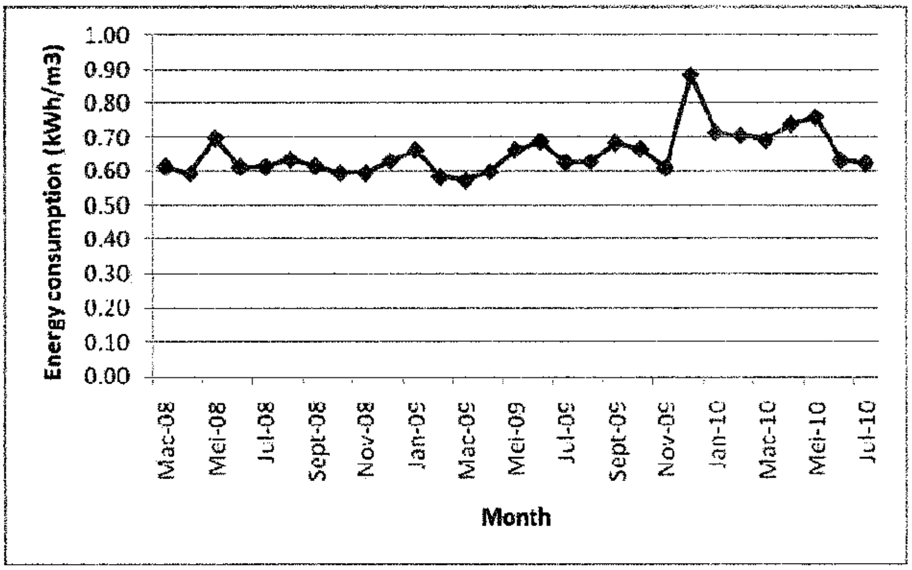
- Current and voltage data are average of 5 readings taken at an interval of 1 hour each

Appendix 4.2 Previous energy audit: Pantai Dalam power consumption data and energy use distribution 2008-2010

Facility	Total energy (kWh/day)
Aeration Tank	21,453.00
Pump Station	19,600.00
Secondary Clarifier	2,941.40
Mechanical & Gravity Thickener	1,829.28
Dewatering	1,110.75
Digester	737.00
Primary Clarifier	486.28
Tanker Sludge	360.00
Grit Chamber	120.88
Measuring Tank	105.60
Odour Scrubber	96.00
Total	**48,840.18**



Appendix 4.3 Previous energy audit: Pantai Dalam energy consumption per cubic meter of influent and project objective



Project objective:

To optimize energy consumption while maintaining full compliance with EQA requirement through PDCA cycle approach

Goal setting:

To reduce energy power consumption per cubic meter of influent by 10% from current usage by December 2009

Before project started => 0.72 kWh/m3

Target to reduce by 10% => 0.64 kWh/m3

Appendix 4.4 Calculation for Sewage Lift Pump Operating Points

Sewage lift pump	**Pressure (kPa)**			
	01/07/2011	**15/07/2011**	**08/08/2011**	**Average**
Pump 1	400	390	395	**395**
Pump 2	90	90	90	**90**

- Pressure data are average of 5 readings taken at an interval of 1 hour each

Average raw sewage specific gravity, $SG_{avg} = 1\text{-}1.02$

Head, H $= \frac{P(bar)\times 10.2}{SG_{sewage}}$

$= \frac{3.95\times 10.2}{1}, \frac{0.9\times 10.2}{1}$

$H_1 = 40.3$ m

$H_2 = 9.2$ m

Average flowrate, Q_{avg} $= \frac{2{,}199{,}817m^3}{month} \times \frac{month}{30days} \times \frac{day}{24h} \times \frac{h}{60min}$

$= 50.9\ m^3/min$

Thus, at 100% speed the efficiency (η) is,

$\eta_a = 69\%$

$\eta_o = 82\%$

$kW_{in} = 305$ kW

Savings $= kW_{in} \times t \times (1 - \eta_a/\eta_o)$

Where Savings = energy savings (kWh/month)

kW_{in} = input electrical energy (kW)

t = monthly operating hours

η_a = actual system efficiency, calculated from field measurements

η_o = optimal system efficiency

Thus, Savings $= 305kW \times 24h \times 30 \times (1 - 0.69/0.82)$

= 34,815 kWh/month

$= 34{,}815\ \mathrm{kWh/month} \times \mathrm{RM}0.2305/kWh$

= RM8,024.86/month

By changing it to 90% speed,

$\eta_a = 69\%$

$\eta_o = 80.5\%$

Thus, savings $= 305kW \times 24h \times 30 \times (1 - 0.69/0.805)$

= 31,371 kWh/month

$= 31{,}371\ \mathrm{kWh/month} \times \mathrm{RM}0.2305/kWh$

= RM7,231.02/month

Appendix 4.5 Pump specification

Equipment Name	Contract Specification (CS) (Tender Specification)	
Sewage Lift Pump	Item no.	M1-007-1
	Equipment name	Sewage Lift Pump
	Pump type	Vertical Shaft Mixed Flow Pump
	Pump bore diameter	Dia. 800mm
	Discharge flow	80m3/min
	Total head	20m
	Motor output	400kW
	Pump efficiency	Min. 80%
	Driving method	Electric motor
	Operation	Automatic operation with pump well level and manual switching
	Arrangement	One-floor type
	Column length	10.4m (between pump base and suction end)
	No. of intermediate bearing	3
	Motor type	3-phase squirrel cage induction motor
	Motor output	400 kW
	Motor efficiency	Min. 92% at rated load
	Power supply	415Vx50Hzx3phase
	No. of poles	8P
	Starting method	Soft starter
	Completion date	September, 2007
	Manufacturer	Ebara Corporation