Design Calculation of the Upgraded Equipments for Residue Plant Under Different Operating Capacity

by

Mohd Hanafi Bin Abd Rashid @ Abd Rasip

Dissertation submitted in partial fulfilment of
the requirements for the
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(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(A.P DR. HUSSAIN H AL KAYEM)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

November 2009

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.

MOHD HANAFI B ABD RASHID @ ABD RASIP

ABSTRACT

The increase in demand of residue due to new production of Group III Lube Base Oil Product in Melaka Refinery required the residue plant to increase the feeding capacity of residue to the required unit. For the plant to achieve the targeted flow rate of the residue, the residue plant has upgraded the existing pumping capacity and cooling capacity by installing one unit of centrifugal pump P1112C and one unit of air fin cooler E1129A to support the existing cooling system for the tempered water. The analyses are focusing on the mathematical modelling of the pump and heat exchanger to determine the right specification for the new equipments that are required for the new operating design. The hydraulic work covered the pipelines system from crude column C1101 to storage tank T72211 in order to determine the total head losses along the pipelines and through the equipments connected along the loop. The head of pump and pump-system operating curve at different operating capacity Q has been plotted to determine the operating point for the pump. For thermal capacity analysis of heat exchanger, ratio (old design/new design) for coolant flow has been determined. The analysis for air fin cooler E1129 and E1129A involves some calculations on the internal tube side and also finned tube side.

ACKNOWLEDGEMENTS

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

In the name of Allah, The Beneficent, The Merciful.

Alhamdulillah, all praises to The Almighty for His blessing, give me ability to complete this two (2) semesters of Final Year Project entitle "Design Calculation of the Upgraded Equipments for Residue Plant Under Different Operating Capacity" as one of the requirement for final year students in this Universiti Teknologi PETRONAS.

I would like to seize this great opportunity to thank to all parties who has contributed along the process in completing this project. Special acknowledgment I would like to give to my beloved supervisor A.P Dr. Hussain H al Kayem. He gives trust on me in completing this challenging project besides his complementing, encouraging and motivating words. Special acknowledgement also to Mechanical Engineering Department, especially my examiners, A.P Dr. Fakhruldin b M Hashim and Dr Ahmed Maher Said Ali for their comments and great responses in order to improve my project work. I also want to thank Mr Kamaruzzaman Kassim, Mr Muhammad Helmi b Abu and Mr M Heikal Zulkifli from PETRONAS Penapisan Melaka Sdn Bhd for giving me valuable opportunities to get involve in the upgrading activities of residue plant in Melaka Refinery during my internship time there.

With all the supports and trust I received, Alhamdulillah, this project has been selected to represent Mechanical Engineering Department in Engineering Design Exhibition 24th Edition which has won Silver Award. Apart from that, I would like to express my appreciation to my external examiner, Ir Alzakri Ekhwan from PETRONAS Penapisan Melaka Sdn Bhd for evaluating my Final Year Project, and also to my beloved family and friends who never stop in supporting me. Thank You.

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ABBREVIATIONS

LSWR	Low Sulphur Waxy Residue
PP(M)SB	PETRONAS Penapisan (Melaka) Sdn Bhd
CDU	Crude Distillation Unit
MG3	Melaka Group III
PSR-1	PETRONAS Second Refinery-1
HP	High Pour
TNB	Tenaga Nasional Berhad

CHAPTER 1

INTRODUCTION

New production of Group III Lube Base Oil Products in Melaka Refinery requires the residue plant to increase feeding capacity of residue. The plant has upgraded pumping and cooling capacity by installing a new pump P1112C and air fin cooler E1129A.

1.1 Background of the Loop

Figure 1.1 below shows the new design loop for residue plant. Pump P1112C and air fin cooler E1129A are the new equipments that have been installed at the plant.

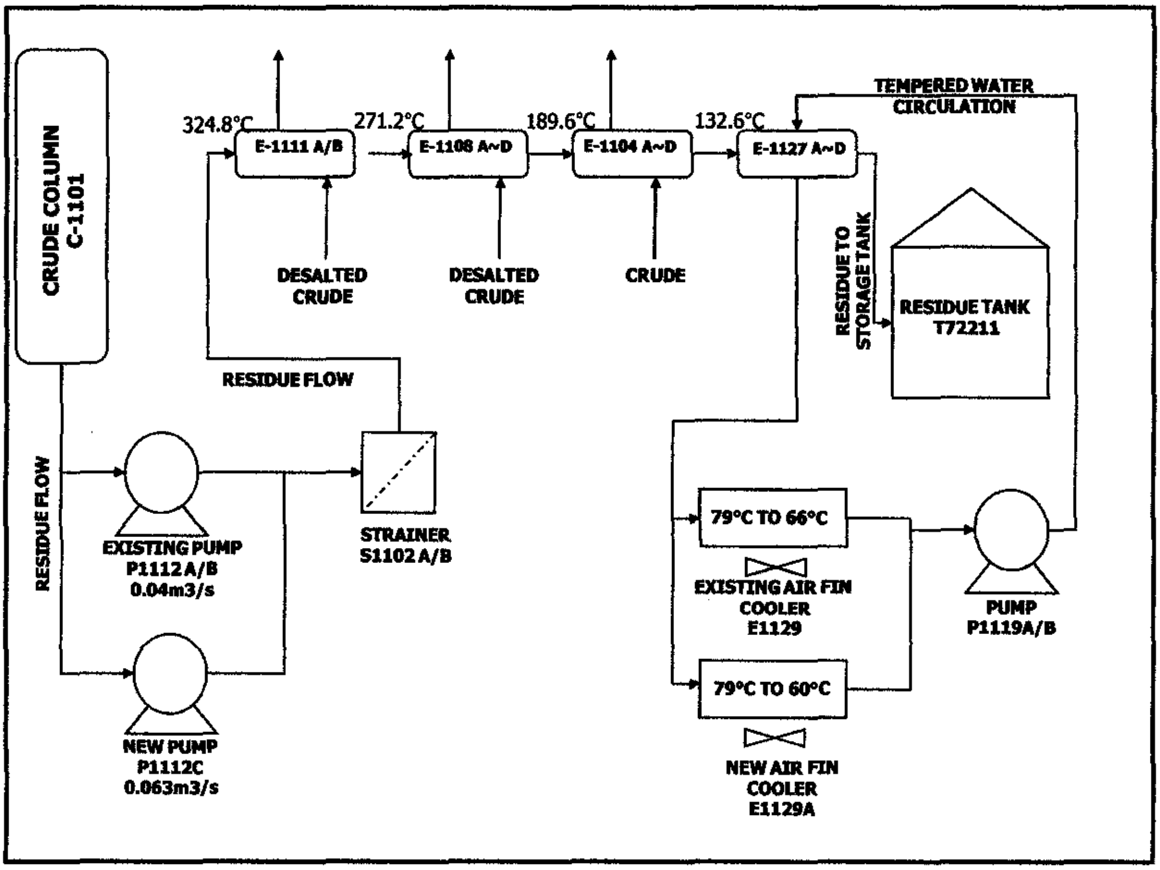


Figure 1.1: New Design of Residue Plant in Melaka Refinery (refer to Project Risk Assessment for High Pour Crude LSWR Rundown System Debottlenecking Project presented by *Kamaruzzaman*, 2008)

1.1.1 Process Philosophy

- The existing flow of residue from crude column C1101 is pumped by P1112A/B with maximum capacity of $0.04 m^3/s$.
- While the new pump P1112C is able to operate with single operation with its maximum operating capacity of $0.063 m^3/s$.
- The flow of residue will flow through two (2) units of strainer S1102A/B with particle size of solid to be retained is $500 \mu m$.
- Then, the residue will flow through a series of heat exchangers which are E1111A/B, E1108A/D, E1104A/D and E1127A/D.
- The flow of coolant passing through each heat exchanger will cool down the residue by heat transfer process.
- The desalted crude is a coolant for E1111A/B and E1108A/D. The temperature of residue is reduced from 324.8 °C to 271.2 °C until it reaches 189.6°C.
- The crude is a coolant for E1104A/D. The temperature of residue is reduced from 189.6°C to 132.6°C.
- The tempered water passing through E1127A/D will cool down the residue flow from 132.6°C to 73°C before entering the storage tank T72211.
- The tempered water is being circulated by two (2) units of pumps P1119A/B.
- The existing air fin cooler E1129 will cool down the tempered water from 79°C to 66°C.
- While the new air fin cooler E1129A is designed to cool down the tempered water from 79°C to 60°C.

1.2 Problem Statement

The objective of Melaka Group III (MG3) Project which started in year 2007 is to upgrade PSR-1 Low Sulphur Waxy Residue (LSWR) to produce Group III Lube Base Oil products (*MG3 Project, Project Status and Challenges Ahead, Management Briefing, 26 June 2007*).

This requires the residue plant in PSR-1 to increase its feeding capacity of LSWR to MG3 Unit. In order to increase that, the residue plant has designed to install a new pump to upgrade its pumping capacity as well as a new air fin cooler to upgrade the cooling capacity for tempered water.

In this project, the study will be focused on the right specification of the new pump and air fin cooler required by the residue plant in order to meet the requirement of the new design by performing some calculations. This is to determine whether the specification of the installed equipments really match the required operating specification.

Figure 1.2: Existing Pumps

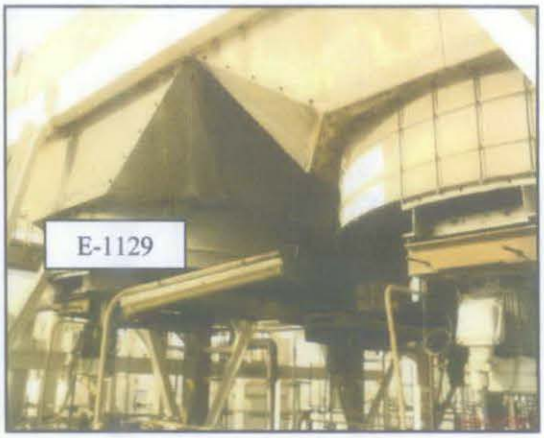


Figure 1.3: Existing Air Fin Cooler

(refer to Project Risk Assessment for HP Crude LSWR Rundown System Debottlenecking Project presented by *Kamaruzzaman*, 2008)

The new pump P1112C is capable to operate at higher operating capacity than P1112A/B with only single operation. The existing two (2) units of pump P1112A/B are set for back-up as shown in Figure1.2 above.

Due to increase in feeding capacity of residue, the existing air fin cooler E1129 as shown in Figure 1.3 above is not capable to cool down the tempered water at the required temperature. Thus, a new air fin cooler E1129A has been installed to upgrade the existing cooling system.

1.3 Objectives

The objectives of this project are:

a) To perform calculation to determine the right specification of pumping capacity for residue pump at various operational flow rate.
b) To perform calculation to determine the required specification of cooling capacity for air fin cooler for the tempered water cooling system.

1.4 Scope of Study

The scope of study is classified as below:

a) Plant Equipment Analysis
   Identify type of equipment, main components, operating principle and the design specification of the equipment.
b) Mathematical formulation involves modeling of piping, pump, heat exchanger and air fin cooler.

CHAPTER 2
LITERATURE REVIEW

The main important process in the residue plant is the distillation process. The residue is a rundown product of the distillation process happen in the crude distillation column C1101.

2.1 Crude Distillation Process

According to K.H.Davis and F.S.Berne, distillation is the first and most fundamental step in the refining process after the crude oil has been cleaned and any remnants of brine removed (Nelson, 1958; Bland and Davidson, 1967; Speight, 1999, and references cited there in; Speight and Ozum, 2002, and references cited there in), which is often referred to as the primary refining process. [22]

Distillation involves the separation of the different hydrocarbon compounds that occur naturally in a crude oil into a number of different fractions (a fraction is often referred to as a cut). The crude distillation unit is the unit in a refinery that receives the crude oil. In this unit, the process of distillation is used to physically separate the crude into different groups of hydrocarbons. This separation is possible because each hydrocarbon group has a different boiling range. [22]

In an atmospheric distillation process, heated crude oil is separated in a distillation column into streams that are then purified, transformed, adapted, and treated in a number of subsequent refining processes, into products for the refinery's market. The lighter, more volatile, products separate out higher up the column, whereas the heavier, less volatile, products settle out towards the bottom of the distillation column. The fractions produced in this manner are known as straight run fractions ranging from (atmospheric tower) gas, gasoline, and naphtha, to kerosene, gas oils add light diesel, and to (vacuum tower) lubricating oil and residuum.[22]

2.1.1 Crude Distillation Column

A typical example of a distillation tower is an atmospheric distillation tower, commonly seen in oil refineries. It separates crude oil into gasoline, naphtha, kerosene, gas oil, and residue. Another example is a vacuum distillation tower. It separates residue from the atmospheric distillation tower, into more valuable products under vacuum conditions. Basically the heaviest components move down the tower, while the lighter components vaporize and move up the tower. [23]. Please refer to Appendix 4 to see the specification of crude column C1101.

2.2 Pump

The new pump P112C is a centrifugal type [15]. Its action depends upon centrifugal action or the variation of pressure due to rotation action or the variation of pressure due to rotation, hence the term 'centrifugal pump'[1]. Please refer to Appendix 5, 6 and 7 to see the specification of pump P1112A/B/C and P1119A/B [11, 12, and 15].

2.3 Heat Exchanger

Heat exchangers E1111, E11108, E1104 and E1127 are shell and tube type, while E1129A and E1129 are air fin coolers type. [14, 18]

2.3.1 Shell and Tube Heat Exchanger

Heat Exchanger E1127 is a U-Tube type [18]. Please refer to Appendix 17 to see design structure of Fixed Tube Sheet Exchanger, Floating Head Type Exchanger and U-Tube Exchanger.

2.3.2 Air Fin Cooler

Air fin cooler can be classified into two (2) types as discussed below.

Forced Draft

The fan is mounted bellow the tubes and air is blown upward across the tubes [2]. The new E1129A is a forced draft type [14]. Figure 2.1 below shows the main components of forced draft aerial cooler.

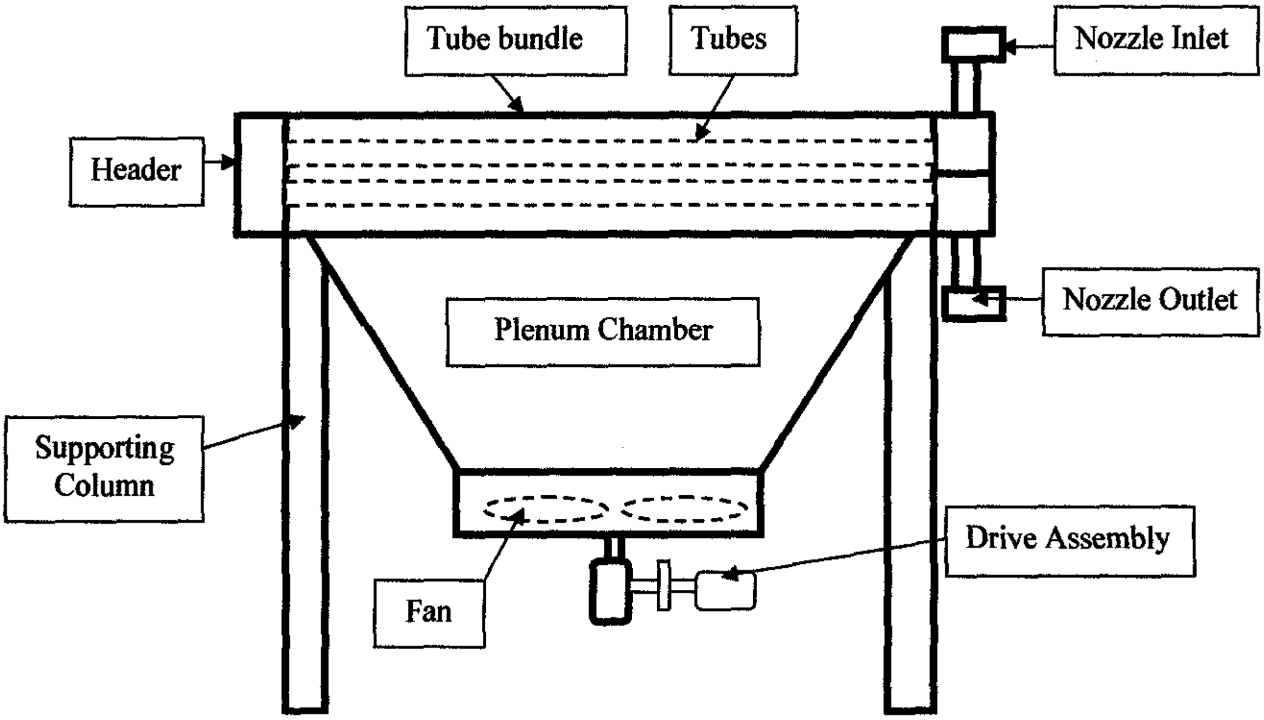


Figure 2.1: Component of Forced Draft Type, Aerial Cooler Heat Exchanger (redraw diagram, refer to PECAS Learning Material, Maintenance of Heat Exchangers)

Induced Draft

The fan is mounted above the tubes and air pulled upward across the tubes. It is more expensive than the other type. However, it is often preferred because it is more efficient since it offers less chance for hot exhaust air being sucked back and drawn through the tubes again. [2]. Figure 2.2 shows the main components of induced draft aerial cooler.

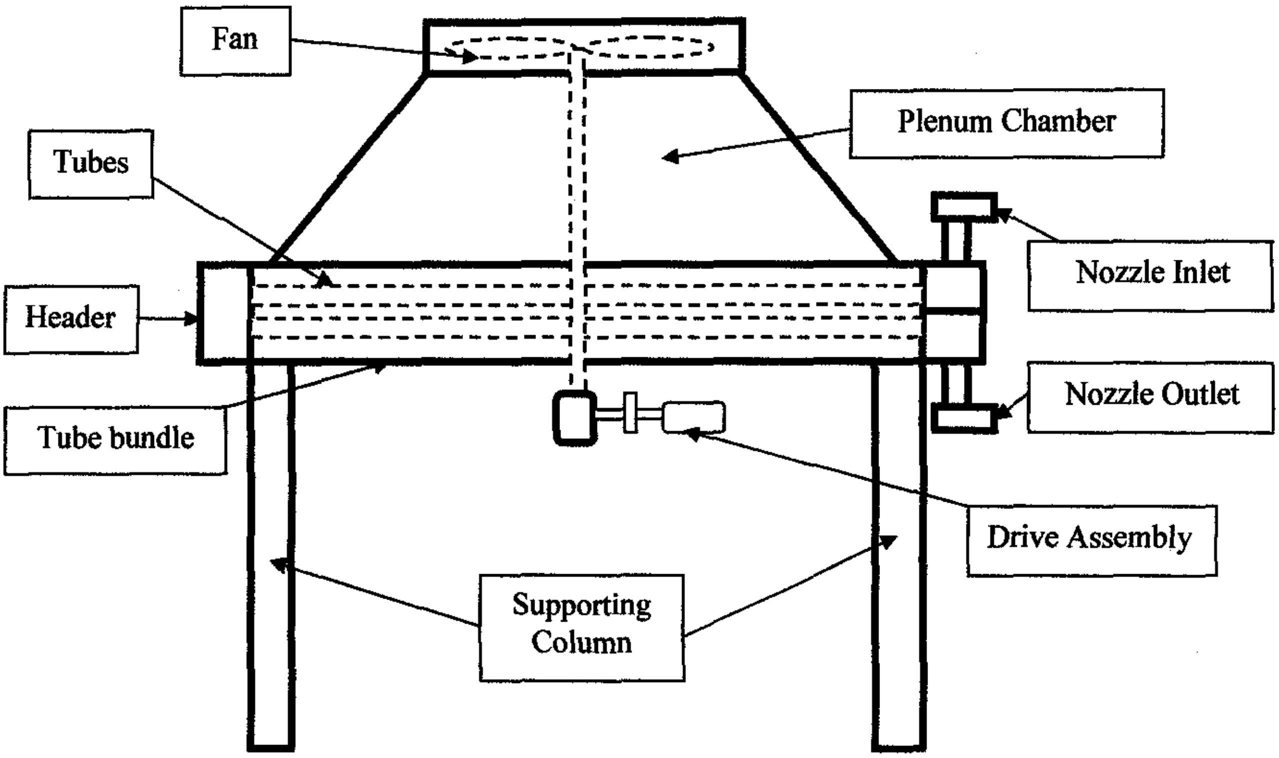


Figure 2.2: Component of Induced Draft Type, Aerial Cooler Heat Exchanger (redraw diagram, refer to PECAS Learning Material, Maintenance of Heat Exchangers)

2.4 Strainer

There are two (2) units of basket strainer type [13] connected in the loop as shown in Figure 2.3.

Figure 2.3: Basket Strainer S1102A/B (refer to Project Risk Assessment for HP Crude LSWR Rundown System Debottlenecking Project presented by *Kamaruzzaman*, 2008)

2.5 Storage Tank

Storage tank T72211 is a cone roof type [16] and it is used to store the residue. Generally, tank can be classified as follows.

2.5.1 Atmospheric Storage

This term is applied to tanks operating at or near atmospheric pressure. It is used to hold liquid which will not vaporize in ambient temperatures. Tanks that fall in this category are primarily the open top, fixed roof (cone and dome) and floating roof. This type of tank has no roof and may store or process non-volatile liquids such as water. [4]. Figure 2.4 shows the component of cone roof storage tank.

2.5.2 Pressure Storage

It is referred to those vessels which are designed to withstand pressure sufficient to keep the liquid stored from vaporizing, high vapor pressure hydrocarbons such as propane, butanes, olefins and etc. [4]

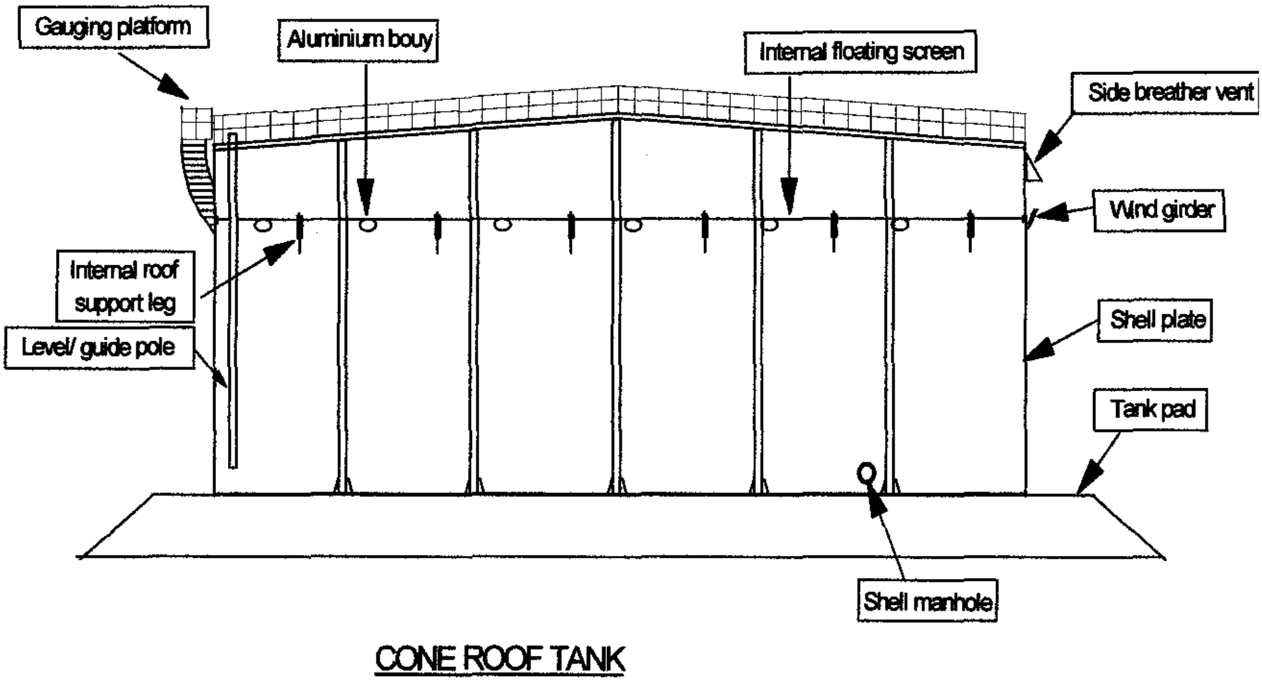


Figure 2.4: Component of Cone Roof Storage Tank (taken from Training Manual, Oil Movement and Storage, Equipment Identification Tank, *Norazmi Mat Noh)*

CHAPTER 3

METHODOLOGY

Discussion on technique of analysis that is going to be applied and the project work flow.

3.1 Technique of Analysis

Based on the nature of the problem, mathematical modeling of the equipments involved in the replacement should be carried out. Then, calculation will be conducted to select the suitable replacing new units. Basically, the work involve in analyses can be divided into two (2) main parts as stated below.

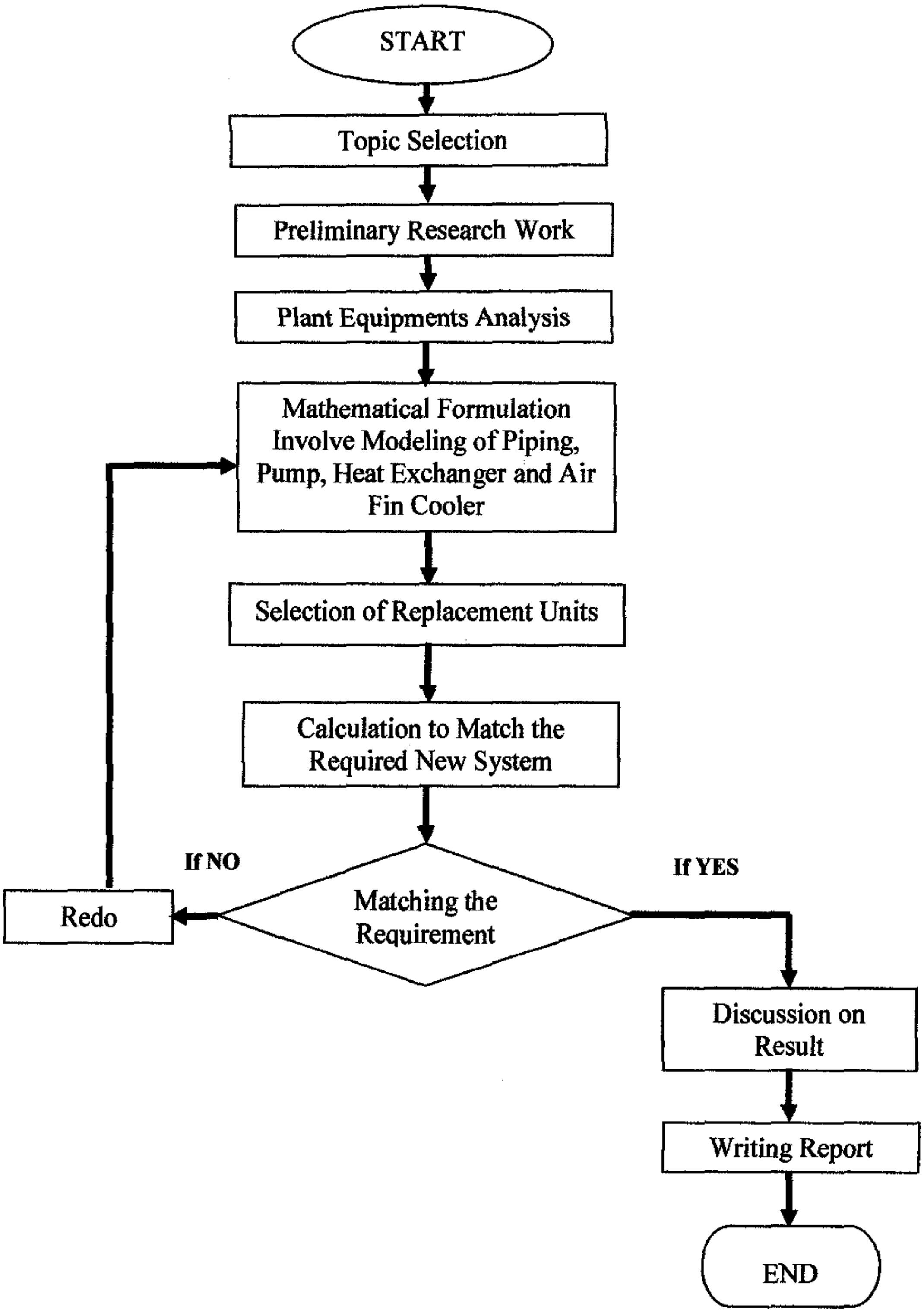
3.1.1 Pump Work

a) Identify diameter at the inlet and outlet, length and connection of the pipelines.
b) Calculate the total head losses h_L along the pipelines and through equipments $h_{L,Equip}$.
c) Energy diagram for residue flow from crude column C1101 to storage tank T72211.
d) Apply Energy equation to determine head of pump at any operating capacity.
e) Plotting pump-system operating curve to determine the operating point of pump.

3.1.2 Thermal Work

a) Determine ratio (Old Design/New Design) for coolant flow through the heat exchangers E1111A/B, E1108A/D, E1104A/D and E1127A/D.
b) Tube analysis on internal side and finned tube side for air fin cooler E1129 and E1129A.

3.2 Execution Flow Chart



3.3 Gantt Chart

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Project work continues: Hydraulic Capacity										MID SEMESTER BREAK					
	➢ Pipe work from crude column to pump	▨														
	➢ Equation of Head losses and Head of pump		▨	▨												
	➢ Energy diagram and Energy equation				▨											
	➢ Plotting Pump-System operating curve				▨											
2	Submission of Progress Report 1					X										
3	Project work continues: Thermal Work				▨	▨	▨	▨	▨	▨						
	➢ Cooling Data for New & Old Design															
	➢ E1111, E1108, E1104, E1127 Cooling Analysis															
4	Submission of Progress Report 2									X						
5	Seminar FYP II									X						
6	Project work continues on E1129, E1129A											▨	▨	▨	▨	▨
	➢ Tube analysis (Internal and finned side)															
7	Poster Exhibition													X		
	➢ Engineering Design Exhibition 24th Edition														X	
8	Submission of Dissertation (soft bound)															X
9	Oral Presentation											2 November 2009				
10	Submission of Project Dissertation											7 days after Oral				

X Suggested milestone

▨ Process

CHAPTER 4

HYDRAULIC CAPACITY CALCULATION

The calculation involving pipeline and pump will be conducted in this chapter. The purpose of installation new pump P1112C is to increase the maximum operating capacity of residue flow from 0.04m3/s to 0.063m3/s. Remind that this new pump shall be located in parallel with the existing pumps P1112 A/B with only single operation.

The objective of the calculation is to determine the head of the pump P1112C at different flow rate. The Energy equation below will be used to calculate the head of the pump at any given flow rate.

$$\frac{(Q/A_1)^2}{2g}+\frac{P_1}{\rho g}+z_1+H_{pump}=\frac{(Q/A_2)^2}{2g}+\frac{P_2}{\rho g}+z_2+h_L$$

Point 1 is referred to the surface at crude column C1101, while point 2 is referred to the surface at the storage tank T72211. From the above equation, the head losses h_L along the pipelines from the crude column C1101 until the inlet of the tank T72211 has to be determined. The flow rate of the residue is constant along the pipelines.

Table 4.1: Properties of Residue

Properties (Fluid)	Residue
Viscosity, kg/m.s	0.0004
Vapor Pressure, kg/m^2.G	18200
Specific Gravity	0.7370
Max. Flow Rate, Q (m^3/s)	0.0633
Density, kg/m^3	737

Table 4.1 above shows the properties of residue. The data will be used in calculation to find the value of head losses, h_L under different operating capacity.

4.1 Characteristics of Pipelines and Flow

For pipe with diameter 0.1524m (6" in size), the velocity and Reynolds Number at operating capacity Q can be determined by using the formulas below. We know the average velocity through the pipeline with cross sectional area, A is as below.

$$V_{avg} = Q/A = 4Q/\pi D^2$$

The flow regime can be determined from Reynolds Number as follow. If the Reynolds Number is greater than 4000, the flow is turbulent.

$$\mathrm{Re} = \frac{\rho . V_{avg} . D}{\mu} = 4\frac{\rho Q}{\pi D \mu} = 4\frac{737 * Q}{\pi * 0.1524 * 0.0004} = 15.39 Q X 10^6$$

The material of the pipe is Alloy (5Cr-1/2Mo). The pipe roughness is 0.045mm (*refer to Table 8-2, Equivalent roughness values for new commercial pipes, Yunus A. Cengel, John M. Cimbala (2006), Fluid Mechanics Fundamentals and Application, Mc Graw Hill International Edition*). The relative roughness of the pipe with diameter of 0.15m (6" in size) is calculated as below.

$$\varepsilon / D = \frac{0.000045m}{0.1524m} = 0.0003$$

Please refer to Appendix 10 for flow and pipeline characteristics at different operating capacity.

4.2 Determine of Friction Factor

The friction factor f corresponds to the calculated relative roughness and the Reynolds Number for specific operating capacity Q is determined by using the Colebrook Equation.

The f_{guess} value needs to be determined by using the equation below.

$$\frac{1}{\sqrt{f_{guess}}} \cong -1.8\log[\frac{6.9}{\mathrm{Re}} + (\frac{\varepsilon/D}{3.7})^{1.11}]$$

The f_{new} value has to be determined by computing the previous f_{guess} into the Colebrook Equation.

$$\frac{1}{\sqrt{f_{new}}} \cong -2.0\log[\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f_{old}}}]$$

The gain f_{new} value is iterated until the convergence is achieved.

Table 4.2: Iteration of Friction Factor for 0.1524m Pipeline at 0.063m3/s

Iteration	f(guess)	f(new)	|f(new)-f(guess)|
1	0.0155	0.0156	0.0001
2	0.0156	0.0156	0.0000

Table 4.2 above shows the iteration for 0.1524m pipeline at 0.063m3/s. The friction factor f has converged to four (4) digits after two (2) iterations. Please refer to Appendix 11 to see the full iteration of friction factor at different operating capacity Q.

4.3 Determine of Head Losses

The pressure drop would need to be calculated for the whole piping from P1112C to T72211 because the increase in flow rate results in increase in pressure drop for the entire circuit (*Maizatul Dalina, Technologist Department, PPMSB, April 22, 2009*). Please refer to Appendix 9 for pipeline connection from Unit 11 of CDU to storage tank T72211 taken from Overall Site Plan for Malaysian Refining Co. Sdn. Bhd with the given scale 1:4000.

Based on the references, the pipeline can be divided into three (3) sections which are:

a) From the crude column C1101 to pump P1112C.
b) From pump P1112C to strainer S1102A/B.
c) From strainer S1102A/B to storage tank T72211.

The major head loss $h_{L,major}$ is determined from the Darcy-Weisbach equation.

$$h_{L,Major} = f\frac{L}{D}\frac{(Q/A_{pipe})^2}{2g}$$

While the minor head loss $h_{L,\min or}$ is determined from the formula below.

$$h_{L,Minor} = K\frac{(Q/A_{pipe})^2}{2g}$$

The length of the pipelines has been estimated by referring to two (2) main sources:

a) Overall Site Plan for PSR-2 Melaka Refinery Project Stage 1 provided by Chiyoda with a scale of 1:4000.
b) Isometric Drawing for HP Crude LSWR Rundown System Debottlenecking Project provided by Ranhill Worley Sdn Bhd.

4.3.1 Pipeline Connection from Crude Column to Storage Tank

The length of the pipelines from crude column C1101 located at Unit 11of CDU to storage tank T72211 is determined through estimation by referring to Overall Site Plan for PSR-2 Melaka Refinery Project Stage 1. Table 4.3 below shows the estimated total length of the pipelines from crude column C1101 to storage tank T72211.

Table 4.3: Pipelines Characteristics from C1101 to T72211

No	Length, m	Connection	Size, m	Area, m^2
1	121.88	Series	0.1524	0.0182
2	15.63	Series	0.1524	0.0182
3	290.63	Series	0.1524	0.0182
4	146.88	Series	0.1524	0.0182
5	146.88	Series	0.1524	0.0182
6	46.88	Series	0.1524	0.0182
7	12.50	Series	0.1524	0.0182
TOTAL	**781.25**			

Table 4.4: Loss Coefficient K along the Pipelines from C1101 to T72211

No	Minor Losses	K	Quantity	Size, m	Area, m^2
1	90 deg Elbow	0.30	7	0.1524	0.0182
2	Gate Valve	0.20	5	0.1524	0.0182

Table 4.4 above shows the loss coefficient K along the pipelines from crude column C1101 to storage tank T72211. The head losses h_L along the pipelines at any operating capacity Q can be determined from the following equation.

$$h_{L,Major} = f\frac{781.25}{0.1524}\frac{\left(Q/0.0182\right)^2}{2*9.81} = 788{,}793.43fQ^2$$

$$h_{L,Minor} = (7*0.3+5*0.2)*\frac{\left(Q/0.0182\right)^2}{2*9.81} = 477.00Q^2$$

4.3.2 Pipelines Connection from Pump to Strainer

The characteristic of the pipelines from P1112C to S1102A/B is determined by referring to Isometric Drawing for HP Crude LSWR Rundown System Debottlenecking Project. Table 4.5 below shows the characteristic of the pipelines from pump P1112C to strainer S1102A/B.

Table 4.5: Pipelines Characteristics from P1112C to S1102A/B

No	**Drawing No**	**Length, m**	**Connection**	**Size, m**	**Area, m^2**
1	11-360-022-0001-D-1	16	Series	0.1524	0.0182
2	11-1360-001-807	3	Series	0.1524	0.0182
3	11-1360-001-808	3	Series	0.1524	0.0182

Table 4.6: Loss Coefficient K along the Pipelines from P1112C to S1102A/B

No	**Drawing No**	**Minor Losses**	**K**	**Quantity**	**Size, m**	**Area, m^2**
1	11-360-022-0001-D-1	45 deg Elbow	0.40	2	0.1524	0.0182
2	11-360-022-0001-D-1	90 deg Elbow	0.30	5	0.1524	0.0182
3	11-360-022-0001-D-1	Gate Valve	0.20	1	0.1524	0.0182
4	11-1360-001-807	90 deg Elbow	0.30	1	0.1524	0.0182
5	11-1360-001-808	90 deg Elbow	0.30	1	0.1524	0.0182

Table 4.6 above shows the loss coefficient K along the pipelines from pump P1112C to strainer S1102A/B. The head losses along the pipelines at any operating capacity Q can be determined as below.

$$h_{L,Major} = f\frac{22}{0.1524}\frac{(Q/0.0182)^2}{2*9.81} = 22{,}212.42fQ^2 meter$$

$$h_{L,Minor} = (2*0.4+5*0.3+0.2+0.3+0.3)*\frac{(Q/0.0182)^2}{2*9.81} = 477.00Q^2 meter$$

4.3.3 Head Losses through Equipments

The residue flow from crude column C1101 is pumped by a new pump P1112C. The residue will flow through two (2) units of basket strainer S1102A/B and a series of heat exchangers E1111A/B, E1108A/D, E1104A/D, and E1127A/D before entering the storage tank T72211. The pressure drop through equipments will be considered in the calculation of total head losses h_L along the pipelines network.

Table 4.7: Pressure Drop and Total Head Loss through the Equipments

No	Equipment No	Pressure Drop, kg/ m^2	Quantity	Head Loss, m
1	C 1101	46332.27	1	6.41
2	P 1112 C	147342.27	1	20.38
3	S 1102 A/B	12332.27	2	3.41
4	E 1111 A/B	21582.27	2	5.97
5	E 1108 A/D	21582.27	4	11.94
6	E 1127 A/D	21582.27	4	11.94
	Total	270753.62		60.05

Table 4.7 above shows the total pressure drop and total head loss through the equipments. The total head loss through the equipments is 60.05m which can be determined from the following formula.

$$h_{L,Equip} = \frac{\Delta P_L}{\rho_{LSWR} g} = \frac{46332 + 147342 + 2*12332 + 4*21582 + 4*21582}{737*9.81} = 60.05 meter$$

The minor head losses at the inlet and outlet of the equipments need to be considered as well. The loss coefficient, K of the sudden expansion and contraction connected to the equipments through pipeline can be determined using the following formula.

$$K_L = \left(1 - \frac{d^2}{D^2}\right)^2$$

Table 4.8 below shows the loss coefficient K at the inlet and outlet of the equipments.

Table 4.8: Loss Coefficient, K through the Equipments

No	Minor Losses	K	Qty	Size, m	Area, m^2
1	Crude Tower Outlet	0.5000	1	0.8700	0.5942
2	Sudden Contraction at C 1101	0.9396	1	0.8700 X 0.1524	0.5942 X 0.0182
3	Pump Suction	0.5000	1	0.1524	0.0182
4	Pump Discharge	1.0000	1	0.1016	0.0081
5	Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.0182 X 0.0081
6	Strainer Inlet	0.8000	1	0.1524	0.0182
7	Strainer Outlet	1.0000	1	0.1524	0.0182
8	Sudden Expansion at E1111A/B	0.1914	2	0.1524 x 0.2032	0.0182 X 0.0324
9	Sudden Contraction at E1111A/B	0.1914	2	0.2032 x 0.1524	0.0324 X 0.0182
10	Sudden Expansion at E1108A/D	0.1914	4	0.1524 x 0.2032	0.0182 X 0.0324
11	Sudden Contraction at E1108A/D	0.1914	4	0.2032 x 0.1524	0.0324 X 0.0182
12	Sudden Expansion at E1104A/D	0.1914	4	0.1524 x 0.2032	0.0182 X 0.0324
13	Sudden Contraction at E1104A/D	0.1914	4	0.2032 x 0.1524	0.0324 X 0.0182
14	Sudden Expansion at E1127A/D	0.1914	4	0.1524 x 0.2032	0.0182 X 0.0324
15	Sudden Contraction at E1127A/D	0.1914	4	0.2032 x 0.1524	0.0324 X 0.0182
16	Tank Inlet	1.0000	1	0.1524	0.0182

The minor head losses along the pipelines at any operating capacity Q can be determined from the following equation.

$$h_{L,Miinor} = (0.5+0.9396)*\frac{(Q/0.5942)^2}{2*9.81} + (0.5+0.3086+0.8+1.0+14*0.1914+1.0)*\frac{(Q/0.0182)^2}{2*9.81} + \frac{(Q/0.0081)^2}{2*9.81} + (14*0.1914)*\frac{(Q/0.0324)^2}{2*9.81} = 109789Q^2\,meter$$

4.3.4 Total Head Losses

The total head loss h_L is the summation of the major and minor head loss along the pipelines with the losses through the equipments from crude column C1101until the storage tank T72211. Total of major and minor head losses along pipelines and the total head losses through equipments at different operating capacity are as below.

$$h_{L,Major} = (788{,}793.43 + 22{,}212.42) fQ^2 + 60.05 = 811{,}065.9 fQ^2 meter$$
$$h_{L,Minor} = (477.00 + 477.00 + 1097.89) Q^2 = 2{,}051.89 Q^2 meter$$
$$h_{L,Equip} = 60.05 meter$$

The total head losses along the pipelines at any operating capacity Q is the summation of all head losses.

$$h_{Losses} = h_{L,Major} + h_{L,Minor} + h_{L,Equip} = 811{,}065.9 fQ^2 + 2{,}051.89 Q^2 + 60.05 meter$$

4.4 Determine of Operating Parameters

The following diagram of Figure 4.1 shows the path undergoes by the residue flow from the crude column C1101 until storage tank T72211. Point 1 refers to free surface at crude column C1101 while point 2 is at the free surface of the storage tank, T72211. Table 4.9 below shows the simplified parameters from the Energy diagram to be computed into the Energy equation.

Table 4.9: Parameters from the Energy Diagram

Parameter	Column Surface	Tank Surface
Pressure, P (kg/m2)	0	0
Elevation, Z (m)	63.29	20.82
Velocity, v (m/s)	0	0

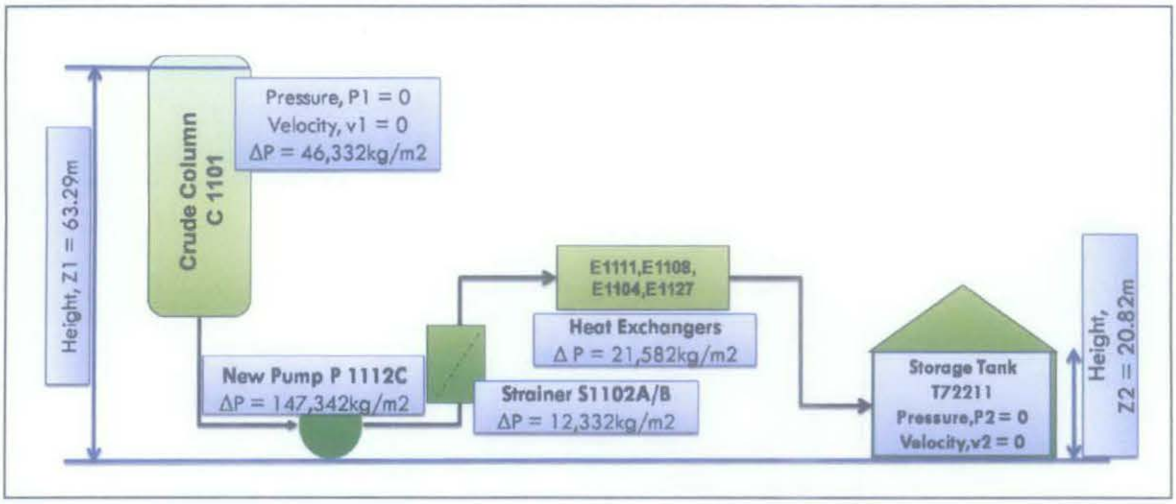


Figure 4.1: Energy Diagram for the Residue Flow from Crude Column C1101 until Storage Tank T72211

The head of pump H_{pump} can be determined by considering as well the total head losses h_L along the pipeline system and computing the required parameters in the Energy equation below.

$$\frac{(Q/A_1)^2}{2g}+\frac{P_1}{\rho g}+z_1+H_{pump}=\frac{(Q/A_2)^2}{2g}+\frac{P_2}{\rho g}+z_2+h_{L,Major}+h_{L,Minor}+h_{L,Equip}$$

$$\frac{0}{2(9.81)}+\frac{0}{9.81*737}+63.29+H_{pump}=$$

$$\frac{0}{2(9.81)}+\frac{0}{9.81*737}+20.82+811{,}065.9fQ^2+2{,}051.89Q^2+60.05$$

The head of pump H_{pump} at any operating capacity Q is now

$$H_{Pump}=811{,}065.9fQ^2+2{,}051.89Q^2+17.58meter$$

CHAPTER 5

THERMAL CAPACITY ANALYSES

Thermal capacity analyses will include the cooling process of residue through series of heat exchangers E1111A/B, E1108A/D, E1104A/D and E1127A/D before entering the storage tank T72211. The tempered water cooling system which equipped with two (2) units of air fin coolers E1129 and E1129A (new) will also be covered in the analyses.

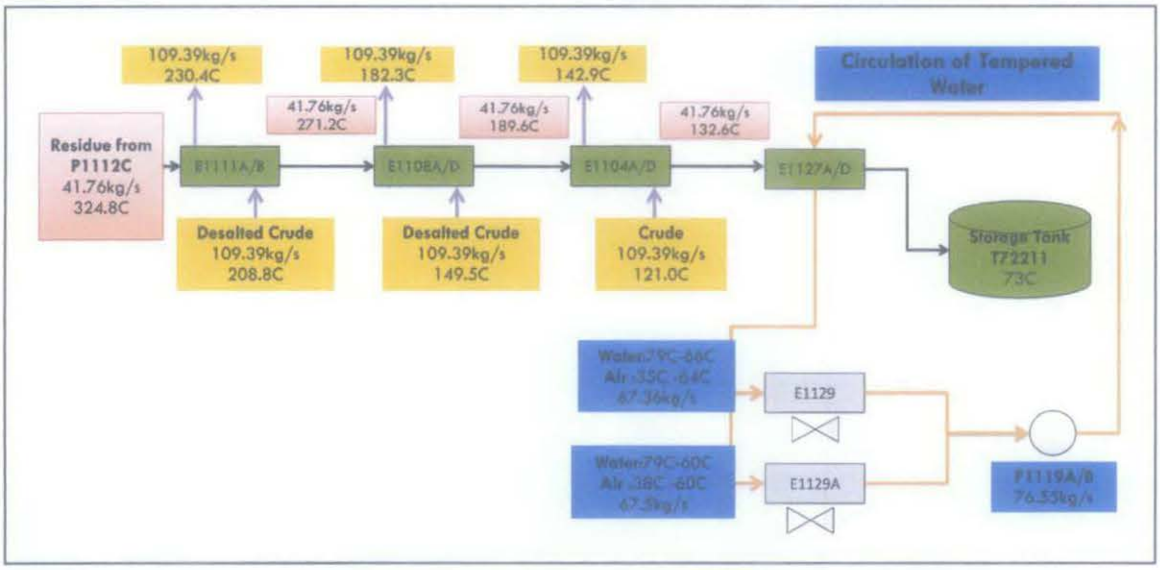


Figure 5.1: New Design of Cooling System of the Residue and Tempered Water

Figure 5.1 above shows the residue flow from pump P1112C through heat exchangers before entering the storage tank T72211.

5.1 Heat Exchanger Analysis

The residue is flow through a series of heat exchangers before entering the storage tank which are E1111A/B, E1108A/D, E1104A/D and E1127A/D. Analysis will be conducted for each heat exchanger.

5.1.1 Specific Heat of Residue and Coolant

The specific heat for the tempered water is given as $4.19\,kJ/kg.°C$. The specific heat for residue can be determined by conducting simple calculation using the data from the old design at E1127A/D.

$$\dot{m}_{hot,old}\, c_{p,hot} \Delta T_{hot,old} = \dot{m}_{cold,old}\, c_{p,cold} \Delta T_{cold,old}$$
$$26.67 * c_{p,residue} * 51 = 61.41 * 4.19 * 13$$
$$c_{p,residue} = 2.459\,kJ / kg.°C$$

The specific heat for desalted crude (coolant through E1111A/B and E1108A/D) can be determined by conducting simple calculation using the data from the new design at E1111A/B.

$$\dot{m}_{hot,new}\, c_{p,hot} \Delta T_{hot,new} = \dot{m}_{cold,new}\, c_{p,cold} \Delta T_{cold,new}$$
$$41.76 * 2.459 * 53.6 = 109.39 * c_{p,desalt.crude} * 21.6$$
$$c_{p,desalt.crude} = 2.33\,kJ / kg.°C$$

The specific heat for crude (coolant through E1104A/D) can be determined by conducting simple calculation using the data from the new design at E1104A/D.

$$\dot{m}_{hot,new}\, c_{p,hot} \Delta T_{hot,new} = \dot{m}_{cold,new}\, c_{p,cold} \Delta T_{cold,new}$$
$$41.76 * 2.459 * 57.1 = 109.39 * c_{p,crude} * 21.9$$
$$c_{p,crude} = 2.448\,kJ / kg.°C$$

5.1.2 Mass Flow Rate of Coolant Flow

The specific heat of residue that has been calculated before can be used to determine the mass flow rate of the coolant flow at heat exchangers E1111A/B, E1108A/D and E1104A/D for the old design. At E1111A/B, the mass flow rate of desalted crude is calculated as follow.

$$\dot{m}_{hot,old}\ c_{p,hot}\Delta T_{hot,old} = \dot{m}_{cold,old}\ c_{p,cold}\Delta T_{cold,old}$$

$$26.67 * 2.459 * 80 = \dot{m}_{desalt.crude,old} * 2.33 * 18$$

$$\dot{m}_{desalt.crude,old} = 125.13 kg / s$$

For E1108A/D, the mass flow rate of desalted crude is calculated as follow.

$$\dot{m}_{hot,old}\ c_{p,old}\Delta T_{hot,old} = \dot{m}_{cold,old}\ c_{p,cold}\Delta T_{cold,old}$$

$$26.67 * 2.459 * 84 = \dot{m}_{desalt.crude,old} * 2.33 * 5$$

$$\dot{m}_{desalt.crude,old} = 472.98 kg / s$$

For E1104A/D, the mass flow rate of crude is calculated as follow.

$$\dot{m}_{hot,old}\ c_{p,old}\Delta T_{hot,old} = \dot{m}_{cold,old}\ c_{p,cold}\Delta T_{cold,old}$$

$$26.67 * 2.459 * 42 = \dot{m}_{desalt.crude,old} * 2.448 * 8$$

$$\dot{m}_{crude,old} = 140.66 kg / s$$

Table 5.1: Flow Characteristics Comparison between Old and New Design through Heat Exchangers

FLOW CHARACTERISTICS FOR NEW DESIGN

HEX E1111A/B	Hot Flow		Coolant	
Fluid	Residue		Desalted Crude	
Temp (In/Out), °C	324.80	271.20	208.80	230.40
Change Temp, °C	53.60		21.60	
Mass Rate (In/Out), kg/s	41.76	41.76	109.39	109.39

HEX E1108A/D	Hot Flow		Coolant	
Fluid	Residue		Desalted Crude	
Temp (In/Out), °C	271.20	189.60	149.50	182.30
Change Temp, °C	81.60		32.80	
Mass Rate (In/Out), kg/s	41.76	41.76	109.39	109.39

HEX E1104A/D	Hot Flow		Coolant	
Fluid	Residue		Crude	
Temp (In/Out), °C	189.60	132.50	121.00	142.90
Change Temp, °C	57.10		21.90	
Mass Rate (In/Out), kg/s	41.76	41.76	109.39	109.39

HEX E1127A/D	Hot Flow		Coolant	
Fluid	Residue		Temp Water	
Temp (In/Out), °C	132.60	72.90	66.00	77.90
Change Temp, °C	59.70		11.90	
Mass Rate (In/Out), kg/s	41.76	41.76	105.56	105.56

FLOW CHARACTERISTICS FOR OLD DESIGN

HEX E1111A/B	Hot Flow		Coolant	
Fluid	Residue		Desalted Crude	
Temp (In/Out), °C	336.00	256.00	177.00	195.00
Change Temp, °C	80.00		18.00	
Mass Rate (In/Out), kg/s	26.67	26.67	125.13	125.13

HEX E1108A/D	Hot Flow		Coolant	
Fluid	Residue		Desalted Crude	
Temp (In/Out), °C	256.00	172.00	154.00	159.00
Change Temp, °C	84.00		5.00	
Mass Rate (In/Out), kg/s	26.67	26.67	472.98	472.98

HEX E1104A/D	Hot Flow		Coolant	
Fluid	Residue		Crude	
Temp (In/Out), °C	172.00	130.00	122.00	130.00
Change Temp, °C	42.00		8.00	
Mass Rate (In/Out), kg/s	26.67	26.67	140.66	140.66

HEX E1127A/D	Hot Flow		Coolant	
Fluid	Residue		Temp Water	
Temp (In/Out), °C	130.00	79.00	66.00	79.00
Change Temp, °C	55.00		13.00	
Mass Rate (In/Out), kg/s	26.67	29.78	61.41	61.41

Table 5.1 shows the comparison of flow characteristics between the old design and the new design through each heat exchanger E1111A/B, E1108A/D, E1104A/D and E1127A/D.

5.1.3 Ratio (Old Design/New Design) for Coolant Flow

The ratio of old design/new design is derived from the following equations.

Old design, $\dot{m}_{hot,old}\, c_{p,hot} \Delta T_{hot,old} = \dot{m}_{cold,old}\, c_{p,cold} \Delta T_{cold,old}$

New design, $\dot{m}_{hot,new}\, c_{p,hot} \Delta T_{hot,new} = \dot{m}_{cold,new}\, c_{p,cold} \Delta T_{cold,new}$

For ratio of (Old design/New design)

$$\frac{\dot{m}_{hot,old}\, c_{p,hot} \Delta T_{hot,old}}{\dot{m}_{hot,new}\, c_{p,hot} \Delta T_{hot,new}} = \frac{\dot{m}_{cold,old}\, c_{p,cold} \Delta T_{cold,old}}{\dot{m}_{cold,new}\, c_{p,cold} \Delta T_{cold,new}}$$

The ratio is determined within two (2) assumptions as shown below.

a) Assuming $\dot{m}_{coolant}$ is same for old flow and new flow.

$$\frac{\dot{m}_{hot,old}\, \Delta T_{hot,old}}{\dot{m}_{hot,new}\, \Delta T_{hot,new}} = \frac{\Delta T_{cold,old}}{\Delta T_{cold,new}}$$

The ratio will shows changes in change of temperature of the coolant flow between the old and new design.

b) Assuming $\Delta T_{coolant}$ is same for old flow and new flow.

$$\frac{\dot{m}_{hot,old}\, \Delta T_{hot,old}}{\dot{m}_{hot,new}\, \Delta T_{hot,new}} = \frac{\dot{m}_{cold,old}}{\dot{m}_{cold,new}}$$

The ratio will shows changes in flow rate of coolant flow between the old and new design.

5.2 Air Fin Cooler Analysis

A new air fin cooler E1129A has been installed to support the existing cooling system to achieve the targeted temperature for the tempered water. The analysis will be conducted for both air fin coolers E1129 and E1129A to determine the required operating power and right size for the fan.

5.2.1 Air Fin Cooler E1129 Flow Characteristics

Table 5.2 below shows the flow characteristics at existing air fin cooler E1129.

Table 5.2: Flow Characteristics through E1129

E1129	Fluid	Flow Rate (kg/s)	Temp In (^{o}C)	Temp Out (^{o}C)
Hot Flow	Water	67.36	79	66
Cold Flow	Air	104.70	35	64

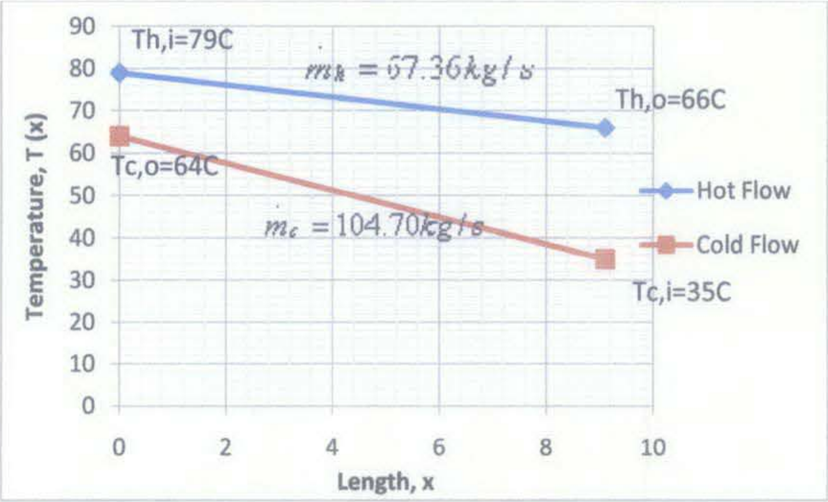


Figure 5.2: Temperature Distribution of Flow for E1129

Figure 5.2 above shows the temperature distribution of flow for the existing air fin cooler E1129.

5.2.2 Air Fin Cooler E1129A Flow Characteristics

Table 5.3 above shows the flow characteristics at new air fin cooler E1129A.

Table 5.3: Flow Characteristics through E1129A

E1129A	**Fluid**	**Flow Rate (kg/s)**	**Temp In ($^{\circ}C$)**	**Temp Out ($^{\circ}C$)**
Hot Flow	Water	67.50	79	60
Cold Flow	Air	166.04	38	60

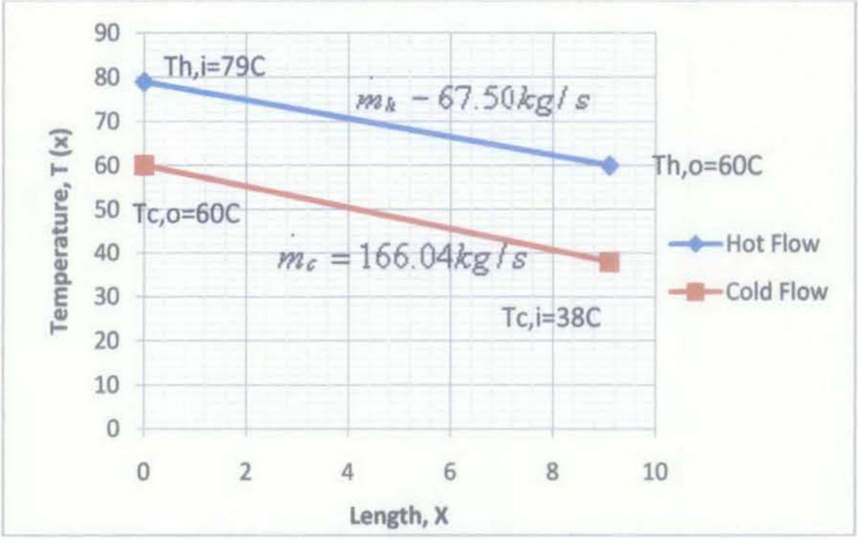


Figure 5.3: Temperature Distribution of Flow for E1129A

Figure 5.3 above shows the temperature distribution of flow for new air fin cooler E1129A.

CHAPTER 6
RESULTS AND DISCUSSION

The result of analyses will be discussed in this chapter involving the hydraulic work and thermal work.

6.1 Results

The result can be classified into three (3) sections which are Pump P1112C Performance Curve, Heat Exchanger Analysis and Air Fin Cooler Analysis.

6.1.1 Pump P1112C Performance Curve

Table 6.1 below shows the head of pump H_{Pump} calculated at different operating capacity. The system curve is multiplied with the safety factor of 1.3.

Table 6.1: Head of Pump at Different Operating Capacity

Capacity, Q (m3/s)	0	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10
H_{Design} **(m)**	243	243	240	238	230.	215	198	165	120	-
$H_{Calculate}$ **(m)**	17.6	19.7	25.6	35.3	48.6	65.7	86.4	110.8	138.1	170.7
$H \times 1.3$ **(m)**	22.9	25.6	33.6	45.9	63.2	85.7	112.3	144.0	179.6	221.9

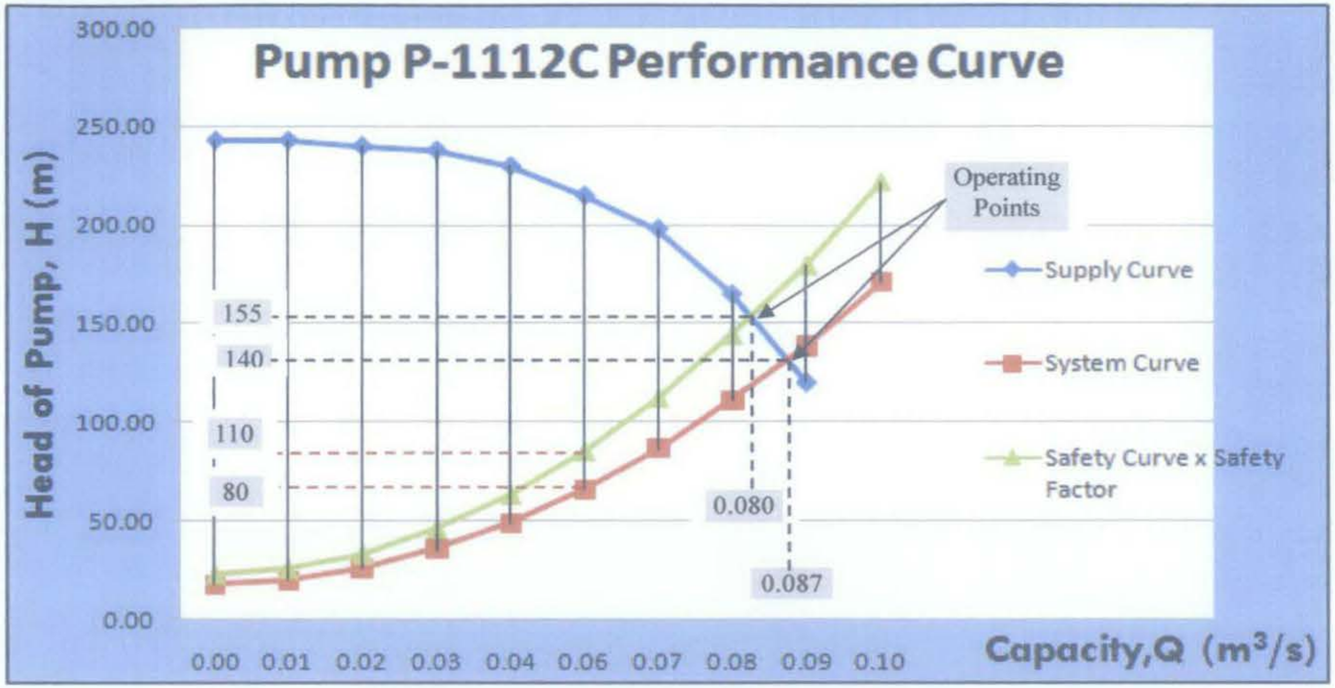


Figure 6.1: Pump P1112C Performance Curve

Figure 6.1 shows the pump P1112C performance curve at various operating capacity Q. The supply curve is from the pump manufacturer while the supply curve is gain from the calculation. The supply curve is multiplied with safety factor of 1.3. The intersection point represents the operating point of the pump system.

6.1.2 Ratio for Coolant Flow

Table 6.2 below shows the ratio for coolant flow at constant flow rate of coolant flow.

Table 6.2: Ratio for Coolant Flow at Constant Flow Rate of Coolant Flow

HEX	m*ΔT(old)	m*ΔT (new)	Ratio
E1111	2133.36	2238.34	0.95
E1108	2240.02	3407.62	0.66
E1104	1120.01	2380.32	0.47
E1127	1466.68	2488.90	0.55

Table 6.3 below shows the ratio for coolant flow at constant change of temperature of coolant flow.

Table 6.3: Ratio for Coolant Flow at Change of Temperature of Coolant Flow

HEX	m*ΔT(old)	m*ΔT (new)	Ratio
E1111	2133.36	2238.34	0.95
E1108	2240.02	3407.62	0.66
E1104	1120.01	2380.32	0.47
E1127	1466.68	2488.90	0.55

6.1.3 Air Fin Cooler E1129 Analysis

The calculation has been conducted as below.

Properties

Water $\bar{T}_h = 72.5°C = 345.5K : c_{p,h} = 4191 J/kg.K$

Air $\bar{T}_c = 49.5°C = 322.5K : c_{p,c} = 1008 J/kg.K$

Internal Tube Side

The hot side convection coefficient inside the tube maybe estimated from an internal flow correlation. With Reynolds's Number

$$\mathrm{Re}_D = \frac{4\dot{m}}{\Pi D \mu} = \frac{4 * 67.36 kg/s}{\Pi * 0.0254m * 389 \times 10^{-6} N.s/m^2} = 8.68 \times 10^6$$

The flow is turbulent and from equation below

$$Nu_D = 0.023 \mathrm{Re}_D^{0.8} \mathrm{Pr}^{0.4} = 0.023 * (8.68 \times 10^6)^{0.8} (2.45)^{0.4} = 1.17 \times 10^4$$

Hence, the convection coefficient

$$h_i = Nu_D \frac{k}{D} = 1.17 \times 10^4 * \frac{0.668 W/m.K}{0.0254m} = 3.077 \times 10^5 W/m^2.K$$

Finned Tube Side

To determine minimum heat capacity rate, we begin by computing

$$C_{cold} = \dot{m}_{cold}\, c_{p,cold} = 104.70 * 1008 = 1.055 \times 10^5 W/K$$

$$C_{hot} = \dot{m}_{hot}\, c_{p,hot} = C_{cold} \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{h,o}} = 105{,}537.6 * \frac{64-35}{79-66} = 2.354 \times 10^5 W/K$$

$$C_{cold} = C_{\min}$$

The maximum heat transfer

$$q_{\max} = C_{\min}(T_{h,i} - T_{c,i}) = 1.055 \times 10^5 * (79-35) = 4.643 \times 10^6 W$$

The actual heat transfer

$$q = C_{hot}(T_{h,i} - T_{h,o}) = 2.354 \times 10^5 * (79-66) = 3.06 \times 10^6 W$$

The effectiveness is $\varepsilon = \frac{q}{q_{\max}} = \frac{3.06 \times 10^6}{4.643 \times 10^6} = 0.659$

With $\frac{C_{\min}}{C_{\max}} = \frac{1.055 \times 10^5}{2.354 \times 10^5} = 0.448$

It follows from Figure that $NTU = \frac{U_c A_c}{C_{\min}} \sim 1.5$ where the surface area of the finned tube side is $5133 m^2$. (Please refer to Appendix 6: Specification Sheet for Air Fin Cooler E1129)

The overall heat transfer coefficient based on the air-side surface area is

$$U_c = \frac{1.5 * 1.055 \times 10^5}{5133} = 30.83 W / m^2.K$$

6.1.4 Air Fin Cooler E1129A Analysis

The calculation has been conducted as below.

Properties

Water $\bar{T}_h = 69.5°C = 342.5K : c_{p,h} = 4191 J / kg.K$

Air $\bar{T}_c = 49°C = 322K : c_{p,c} = 1008 J / kg.K$

Internal Tube Side

The hot side convection coefficient inside the tube maybe estimated from an internal flow correlation. With

$$\mathrm{Re}_D = \frac{4\dot{m}}{\Pi D \mu} = \frac{4 * 67.5 kg / s}{\Pi * 0.0254 m * 404.4 \times 10^{-6} N.s / m^2} = 8{,}367 \times 10^6$$

The flow is turbulent and from equation below

$$Nu_D = 0.023 \mathrm{Re}_D^{0.8} \mathrm{Pr}^{0.4} = 0.023 * (8{,}367 \times 10^6)^{0.8} (2.56)^{0.4} = 1.156 \times 10^4$$

Hence, the convection coefficient

$$h_i = Nu_D \frac{k}{D} = 1.156\times10^4 * \frac{0.664W/m.K}{0.0254m} = 3.022\times10^5 W/m^2.K$$

Finned Tube Side

To determine minimum heat capacity rate, we begin by computing

$$C_{cold} = \dot{m}_{cold}\, c_{p,cold} = 166.04 * 1008 = 1.674\times10^5 W/K$$

$$C_{hot} = \dot{m}_{hot}\, c_{p,hot} = C_{cold}\frac{T_{c,o}-T_{c,i}}{T_{h,i}-T_{h,o}} = 1.674\times10^5 * \frac{60-38}{79-60} = 1.938\times10^5 W/K$$

$$C_{cold} = C_{\min}$$

The maximum heat transfer

$$q_{\max} = C_{\min}(T_{h,i}-T_{c,i}) = 1.674\times10^5 * (79-38) = 6.863\times10^6 W$$

The actual heat transfer

$$q = C_{hot}(T_{h,i}-T_{h,o}) = 1.938\times10^5 * (79-60) = 3.682\times10^6 W$$

The effectiveness is $\varepsilon = \frac{q}{q_{\max}} = \frac{3.682\times10^6}{6.863\times10^6} = 0.537$

With $\frac{C_{\min}}{C_{\max}} = \frac{1.674\times10^5}{1.938\times10^5} = 0.864$

It follows from Appendix 19: Graph of Effectiveness versus NTU that $NTU = \frac{U_c A_c}{C_{\min}} \sim 1.25$ where overall heat transfer coefficient based on the air-side surface area is $h_c = 33.69W/m^2.K$. (Pease refer to Appendix 7: Specification Sheet for Air Fin Cooler E1129A)

The surface area of the finned tube side is

$$A_c = \frac{1.25 * 1.674 \times 10^5}{33.69} = 6211 m^2$$

6.2 Discussion

The results from Pump P1112C Performance Curve, Heat Exchanger Analysis and Air Fin Cooler Analysis are discussed.

6.2.1 Pump P1112C Performance Curve

1. Figure 6.1 shows three (3) curves: supply curve, system curve and safety system curve. The safety head of pump is obtained by multiply the calculated head with safety factor of 1.3.

2. The operating capacity from the intersection of supply curve and system curve is 0.087m3/s with operating head 140.00m. The intersection point of the safety curve with system curve is 0.080m3/s with operating head of 155.00m.

3. The error of the operating capacity is calculated as below.
   a) For System Curve

   $$Error = (\frac{0.087 - 0.063}{0.087}) \times 100 = 27.59\%$$

   b) For System Curve x Safety Factor (1.30)

   $$Error = (\frac{0.080 - 0.063}{0.080}) \times 100 = 21.25\%$$

4. Some improvements have been done from the previous result. The head losses along the pipelines from crude column C1101 to storage tank T72211 has been considered in the calculation. The safety factor is set to be 1.3 as for the safety for the calculated design.

5. The operating power for the new pump P1112C to pump the residue at maximum capacity of 0.063m3/s is

   $P_{new} = Q * H_m * 9810 = 0.063m^3 / s * 212.55m * 9810 = 131.36kW$

   The required power to operate the pump at 0.080m3/s is

   $P_{req} = Q * H_m * 9810 = 0.080m^3 / s * 110.00m * 9810 = 86.33kW$

   The waste operating power is

   $P_{waste} = 131.36 - 86.33 = 45.03kW$

6. The annual waste operating cost can be calculated by referring to Appendix 18 Tariff E3-High Voltage Peak/Off-Peak Industrial Tariff provided by Tenaga Nasional Berhad (TNB).

   For all kWh during the peak period = RM 0.266/kWh
   For all kWh during the off-peak period = RM 0.16/kWh
   Annual Waste Cost
   = Waste Cost at Peak + Waste Cost at Off-Peak
   = 9 hr/day*365days/year*45.03E3W*RM 0.266/1E3W.hr +
   15hr/day*365days/year*45.03E3W*RM 0.16/1E3W.hr
   =39,347.66+39,446.28
   =RM 78,793.94

   The calculated annual waste cost for operating the pump is RM78,793.94

6.2.2 Ratio for Coolant Flow

1. For assumption 1: constant flow rate of coolant flow, the change of temp ΔT of the new design is greater than the old design at all heat exchangers.

2. While for assumption 2: constant change of temperature for coolant flow, the mass flow rate of the new design is greater than the old design at all heat exchangers.

6.2.3 Air Fin Cooler Analysis

1. The overall heat transfer coefficient for the air-side surface area at E1129 is

$$U_c = \frac{1.5*1.055\times10^5}{5133} = 30.83W/m^2.K$$

2. The given specification of overall heat transfer coefficient for finned tube side at E1129 is 33.69 W/m2. K

3. The % of differentiation is calculated as below:

$$Error = (\frac{33.69-30.83}{33.69})\times100 = 8.49\%$$

4. The calculated surface area of the finned tube side at E1129A is 6211m2, which is greater than surface area of finned tube at E1129.

5. The % of increment is calculated as below:

$$Error = (\frac{6211-5133}{5133})\times100 = 16.95\%$$

6. By increase the surface area of the finned tube, the cooling capacity of the new air fin cooler E1129A is 16.95% greater than the existing E1129.

CONCLUSIONS & RECOMENDATION

Based on the result from the pump performance curve, the operating capacity of pump at 0.080m3/s and 0.087m3/s are greater than the specification of the new design at 0.063m3/s, thus the OP is over the required capacity.

For operating capacity of pump at 0.063m3/s, the required head of pump is 110m (at safety factor x system curve intersection point).

As recommendation, the installation of a pump with head of pump less than 212.55m can be considered since it can reduces the operating cost of the pump.

The surface area of the finned tube of the new air fin cooler E1129A is 16.95% greater than the existing E1129, thus the cooling capacity is higher.

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APPENDICES

Appendix 1: Specification Sheet for Pump P1112A/B

Table A.1: Process data sheet for P1112A/B

LIQUID CHARACTERISTICS	
Liquid Pumped	LSWR
Pumping Temperature	336
Density at 101	737
Viscosity at 101	0.38
Vapour Pressure at 101	1.82
DESIGN OPERATING CONDITION	
Speed	2970
Capacity	143.3
Tot Min Suction Head	30.2
Tot Max Discharge Head	132.7
Differential Head at 171	102.5
Efficiency at 121 and 171	68
Power Absorbed at Duty	43.3
Power Absorbed at Top of Power Curve,Kw	56
Recomm Power Motor/Turbine	55
NPSH available	33
PUMP DESIGN	
Direction of Rotation(facing driven end)	CCW
No of Stages	Single
Impeller Diameter (Mac/Act/Min)	330.2/292.1/254
Single or Double Volute:Diffuser Type	double
Centre Line or Foot Mounted	Centre Line
Single or Double Suction	Single
Max Allow Casing Working Pressure at 101, bar ca	18
COOLING	
Medium Temperature	35
Medium Pressure	3.5
CONNECTIONS	
Discharge (Size/Flange Class)	4"/ANSI 300
Discharge Position (Facing Driven End)	Top
Suction (Size/Flange Class)	8"/ANSI 300
Suction Position (Facing Driven End)	End
INSPECTION & TEST	
Shut Off Head, m	115
Shut Off Head/Rated Head (%)	112.2
ADDITIONAL INFORMATION	
Suction Specific Speed, rpm	1460
Min Continuous Stable/Thermal Flow, m3/h	40
Capacity at B.E.P (actual impeller), m3/h	190

Appendix 2: Specification Sheet for Pump P1112C

Table A.2: Process data sheet for P1112C

Pump Type	Centrifugal
Connection (Series/Parallel)	Parallel
Operation (Cont/Int)	Continuous
Driver Type	Electric Motor
Volumetric Flow Rate, m^3/hr	Min 60/Max 228/Nor 207
FLUID PROPERTIES @ T=336°C	
Viscosity, (cP)	0.38
Vapor Pressure, kg/cm^2 g	1.82
Specific Gravity	0.737
SUCTION CONDITIONS	
Source Pressure, kg/cm^2 g	2.2
Static Head, kg/cm^2	0.52
Line Losses, kg/cm^2	0.021
Total Suction Pressure, kg/cm^2 g	2.741
Total Suction Head, m	37.18
DISCHARGE CONDITIONS	
End of Line Pressure, kg/cm^2 g	ATM
Static Head, kg/cm^2	1.66
Losses Through Fittings & Equipment, kg/cm^2	13.68
Total Discharge Pressure(+3barg Design Margin), kg/cm^2 g	18.41
Total Discharge Head, m	249.6
NPSH, DIFFERENTIAL PRESSURE AND POWER	
NPSH Available, m	11.83
Design Differential Pressure, kg/cm^2	15.67
Design Differential Head, m	212.55
Hydraulic Power, kW	107.23
Estimated Efficiency, %	75
Estimated Absorbed Power, kW	143
DESIGN CONDITIONS	
Pump Casing Pressure, kg/cm^2	24.7
Pump Casing Temperature, °C	Max 372
Ambient Temperature, °C	Max 38/Min 20

Appendix 3: Specification Sheet for Pump P1119A/B

Table A.3: Process data sheet of pump P1119A/B

LIQUID CHARACTERISTICS	
Liquid Pumped	Water
Pumping Temperature, °C	66
Density at 101,kg/m^2	980
Viscosity at 101, cP	0.42
Vapour Pressure at 101, kg/cm^2 g	0.763
DESIGN OPERATING COND	
Speed, rpm	1470
Capacity, m^3 /hr	281.2
Tot Min Suction Head, m	25.2
Tot Max Discharge Head, m	54.8
Differential Head, m	29.6
Efficiency at 121 and 171,%	80.5
Power Absorbed at Duty, kW	27.5
Recomm Power Motor/Turbine, kW	37
NPSH Available, m	33
PUMP DESIGN	
Direction of Rotation(Facing Driven End)	CCW
No of Stages	1
Impeller Diameter	Max 355.6, Actual 317.5, Min 279.4
Single or Double Volute: Diffuser Type	double
Centre Line or Foot Mounted	Foot
Single or Double Suction	Double
Max Allow Casing Working Pressure at 101	10
COOLING	
Medium Temperature, °C	35
Medium Pressure, kg/cm^2 g	3.5
CONNECTIONS	
Discharge (Size/Flange Class), in	6"/ANSI 250
Discharge Position (Facing Driven End)	Side
Suction (Size/Flange Class), in	8"/ANSI 250
Suction Position (Facing Driven End)	Side
INSPECTION & TEST	
Shut Off Head, m	35
Shut Off Head/Rated Head (%)	118
ADDITIONAL INFORMATION	
Suction Specific Speed, rpm	1217
Min Continuous Stable/Thermal Flow, m3/h	70
Capacity at B.E.P (Actual Impeller), m3/h	360

Appendix 4: Specification Sheet for Strainer S1102A/B

Table A.4: Process data sheet for Strainer S1102A/B

Strainer Type	Single Basket
Service	LSWR Product Strainer
Configuration	Horizontal
OPERATING CASE	
Fluid/Phase	LSWR /Liquid
Volume Flow, m^3/h	228
Pressure, kg/cm^2 g	18.41
Temperature, $^{\circ}C$	336
Specific Gravity @ 336 $^{\circ}C$	0.737
Viscosity @ 336 $^{\circ}C$	0.38
Density @ 336 $^{\circ}C$	737
DESIGN CONDITIONS	
Design Pressure, kg/cm^2 g	24.7
Design Temperature, $^{\circ}C$	372
Line Size (In/Out), in	6
Flange Rating (In/Out)	300
FILTRATION DATA	
Solids	Yes
Nature of Solids	Sludge
Particle size of solid to be retained, μm	500
Clean Pressure Drop, kg/cm^2 g	0.2
Dirty Pressure Drop, kg/cm^2 g	1
Backwash Required	No

Appendix 5: Specification Sheet for Heat Exchanger E1127A-D

Table A.5: Process data sheet of Heat Exchanger E1127A-D

HEX Type	H-AEU CONNECTED IN 1 PARALLEL 1 SERIES	
Code Requirement	ASME SECTION VIII DIV.1	
TEMA Class	R	
	SHELL SIDE	**TUBE SIDE**
Fluid Name	LSWR	TEMPER WATER
Operating Pressure, kg/cm2	2.7	5
Operating Temperature		
Inlet, °C	131	66
Outlet, °C	79	79
Fluid Density, kg/m3	875	1000
Inside Diameter (#1), mm	750	750
Inside Diameter (#2), mm		
Design Pressure (Internal), kg/cm2	15	10
Design Pressure (External), kg/cm2	0.53	1.05
Design Temp, °C	190	120
No of Passes Per Shell	1	2
Corrosion Allowance, mm	3	3
Joint Efficiency	0.85	0.85
Radiography	SPOT	SPOT
Nozzle Inlet, in	8	10
Nozzle Outlet, in	8	10
Tube Outer Diameter (U-tube), mm	19.05	
Tube Thickness, mm	2.11	
Tube Pitch, mm	25.4	
No of Tubes	270	
Tube Length, mm	6096	
Tube Pattern, deg	90	
Baffle Type	Single Segmental	
Baffle Cut (Diameter),(%)	24.6	
Baffle Spacing, mm	259	
No of Baffles	22	
Baffle Diameter, mm	745	
Baffle Thickness, mm	6	
Cut Orientation	Vertical	
Impingement Plate	Yes	
Tie Rod Diameter, mm	13	
Pass Partition Thickness, mm	13	
No of Tie Rods	6	
Tube to Tubesheet Joint Type	I	

Appendix 6: Specification Sheet for Air Fin Cooler E1129

Table A.6: Process data sheet of Air Fin Cooler E1129

Service	TEMPERED WATER
No of Units	1
No of Bay/Unit	1
Type	2 FPCA
Draft	Forced
SURFACE/UNIT	
Finned	5133m2
Bare Tube	221m2
Weight (Empty/Full of Water), kg/unit	19600/20600
Total Heat Exchanged/MTD, kW/°C	3664/ 21.2
OVERALL HEAT TRANSFER RATE	
Finned Tube, W/m2. °C	33.69
Bare Tube (Service/Clean), W/m2. °C	782.25/907.23
TUBE SIDE DATA	
Fluid Circulated	WATER
Total Fluid Entering, kg/h	242486
Temperature (In/Out), °C	79/66
Vapor (In/Out) , kg/h	0/0
Liquid (In/Out) , kg/h	242486/242486
Steam (In/Out) , kg/h	0/0
Water (In/Out) , kg/h	0/0
Non-Condensable (In/Out) , kg/h	0/0
Vapor Mol.Wt.Avg (In/Out) , kg/h	0/0
Avg Viscosity (Liquid/Vapor), MPa.s	0.391/0
Avg Density (Liquid/Vapor), kg/m3	969.54/0
Avg Specific Heat (Liquid/Vapor), kJ/kg. °C	4.19/0
Avg Thermal Conduct (Liquid/Vapor), W/m. °C	.660/0
Latent Heat , kJ/kg	0
Pressure In, kg/cm2 Abs	3.23
Press Drop Allowance, kg/cm2	0.352/0.336
Fouling Resistance, m2. °C/W	0.00018
AIR SIDE DATA	
Total Air Quantity, m3/s (20°C,1atm)	104.7
Air Quantity Per Fan, m3/s	55
Face Velocity, m/s	2.95
Temperature (In/Out),°C	35/64
Actual Static Press, kPa	0.113
Altitude, m	26
SPL at 1m below Fan, dB(A)	85

Appendix 7: Specification Sheet for Air Fin Cooler E1129A

Table A.7: Process data sheet of Air Fin Cooler E1129A

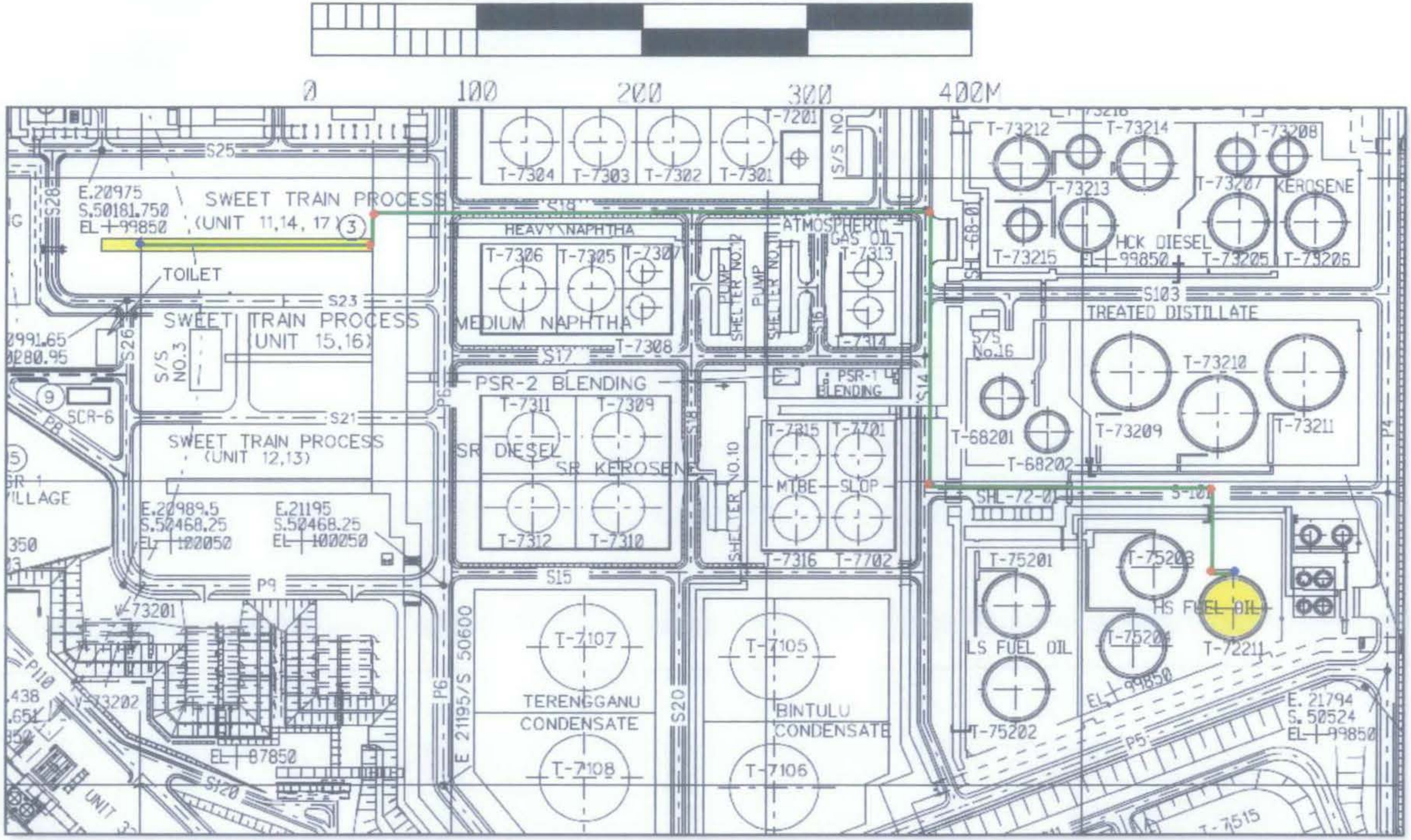
Service	Tempered Water	
Type Draft	Forced	
Bay Size(WxL), m	7.9m x 9.1m	
Heat Exchanged, kW	5374	
SURFACE ITEM: Finned Tube, m2	Note 1	
Bare Tube,m2	430.8	
MTD Effective, $^{\circ}C$	19.5	
TRANSFER RATE: Finned, kW/m^2.$^{\circ}C$	33.69	
Bare Tube, kW/m^2.$^{\circ}C$	Service 782.25, Clean 907.23	
No of Bundle	2	
No of Bay	1	
No of Fan per Bay	2	
TUBE SIDE: Fluid	WATER	
Total Flow Rate, kg/h	243000	
Dew/Buble Point, $^{\circ}C$	151.8	
Operating Pressure, kg/cm^2 g	4	
Latent Heat, kJ/kg. $^{\circ}C$	0	
Inlet Pressure, kg/cm^2 g	4	
Pressure Drop, kg/cm^2 g	0.25	
Velocity, m/s	Note 1	
Inside Fouling Resistance, $m^2.^{\circ}C/W$	0.00018	
Temperature, $^{\circ}C$	IN:79	OUT:60
Water/Stream, kg/h	243000	243000
Density, kg/m^3	970	970
Specific Heat, kJ/kg. $^{\circ}C$	4.19	4.19
Thermal Conductivity, W/m. $^{\circ}C$	0.66	0.66
Viscosity, cP	0.39	0.39
AIR SIDE: No of Fan	2	
Air inlet Temp (Design Dry Bulb), $^{\circ}C$	38	
Air Flow Rate Per Fan, m^3/s	77.2	
Total Air Quantity, m^3/s	154	
Air Outlet Temp, $^{\circ}C$	60	
Face Velocity, m/s	2.72	
Min Design Ambient Temp, $^{\circ}C$	38	
Altitude, m	26	
Static Pressure, mmH$_2$O	11.15	
Total Installed Fan Power, kW	57.6	
Power per Fan, kW	28.8	

Appendix 8: Specification Sheet for Storage Tank T72211

Table A.8: Process data sheet of Storage Tank T72211

Tank No	T-72211
Gross Capacity, m3	24,447
Net Working Capacity, m3	22,258
Internal Diameter, mm	38,300
Height, mm	21,220
Max. Liquid Level (H.L.), mm	20,820
Min. Liquid Level (L.L.), mm	1,500
CONTENTS	
Name	LSWR
Flash Point, $^{\circ}C$	Above 37.8
Storage Temperature, $^{\circ}C$	79/--(HIGH/LOW)
Specific Gravity	0.89
DESIGN CODE	API STD 650 9TH Ed July1993
CODE	BNC
Design Metal Temperature, $^{\circ}C$	104/16.8(HIGH/LOW)
Design Pressure	Atmospheric
Pumping Rate (In/Out), m3/h	2,109/ 91
CORROSION ALLOWANCE	
Shell, mm	1.5
Bottom , mm	1.5
Roof, mm	1.5
Nozzle & Manhole, mm	1.5
Roof Supp. Frame (Each Side), mm	0.75
Shell Design	API STD 650 9th Ed July1993 Variable Design Point Method
Roof Design	
Type	Cone Roof (Truss Supporting Type)
Slope	1/5
Bottom Slope	Cone Down 1/120
Earthquake Factor	API STANDARD 650 APPENDIX "E" 0.075 g,Zone 1 (Z=0.075, I=1.0, S=1.5)
Design Wind Velocity	V10=25m/sec (Wind Speed at 10m)(Category-1,3-Second Gust)
Design Wind Pressure	V10=25m/sec (Wind Speed at 10m)(Category -1,10- Second Gust)

Appendix 9: Estimated Pipelines Connection from Unit 11 of CDU to Storage Tank T72211



Appendix 10: Flow and Pipelines Characteristics at Different Capacity Q

Q (m3/s)	**0.01**	**0.02**	**0.03**	**0.04**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**
Diameter, D (m)	0.1524	0.1524	0.1524	0.1524	0.1524	0.1524	0.1524	0.1524	0.1524
Area, A (m2)	0.0182	0.0182	0.0182	0.0182	0.0182	0.0182	0.0182	0.0182	0.0182
Velocity, (m/s)	0.6094	1.2188	1.8283	2.4377	3.0471	3.6565	4.2659	4.8754	5.4848
Reynold Number, Re	180130	360260	540390	720520	900650	1080780	1260910	1441039	1621169
Type of Flow	Turbulent	Turbulent	Turbulent	Turbulent	Turbulent	Turbulent	Turbulent	Turbulent	Turbulent

Appendix 11: Iteration for Friction Factor at Different Capacity Q

Table 11.1A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.01m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0177	0.0179	0.0002
2	0.0179	0.0179	0.0000

Table 11.2A: Iteration Loop of Friction for Pipe Diameter 0.1524m at 0.02m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0165	0.0167	0.0003
2	0.0167	0.0167	0.0000

Table 11.3A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.03m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0160	0.0162	0.0001
2	0.0162	0.0162	0.0000

Table 11.4A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.04m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0158	0.0159	0.0001
2	0.0159	0.0159	0.0000

Table 11.5A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.06m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0156	0.0157	0.0001
2	0.0157	0.0157	0.0000

Table 11.6A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.07m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0155	0.0156	0.0001
2	0.0156	0.0156	0.0000

Table 11.7A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.08m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0154	0.0155	0.0001
2	0.0155	0.0155	0.0000

Table 11.8A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.09m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0154	0.0154	0.0000

Table 11.9A: Iteration Loop of Friction Factor for Pipe Diameter 0.1524m at 0.10m3/s

Iteration	f (guess)	Corrected f	|f (new)-f (guess)|
1	0.0153	0.0154	0.0001
2	0.0154	0.0154	0.0000

Appendix 12: Head Loss for Pipelines from C 1101 to T 72211 at Different Capacity Q

Table 12.1A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.01m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	0.2712
2	15.63	Series	0.1524	0.0348
3	290.63	Series	0.1524	0.6468
4	146.88	Series	0.1524	0.3269
5	146.88	Series	0.1524	0.3269
6	46.88	Series	0.1524	0.1043
7	12.50	Series	0.1524	0.0278
Total	**781.25**			**1.7386**

Table 12.2A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.02m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	1.0089
2	15.63	Series	0.1524	0.1293
3	290.63	Series	0.1524	2.4057
4	146.88	Series	0.1524	1.2158
5	146.88	Series	0.1524	1.2158
6	46.88	Series	0.1524	0.3880
7	12.50	Series	0.1524	0.1035
Total	**781.25**			**6.4671**

Table 12.3A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.03m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	2.2005
2	15.63	Series	0.1524	0.2821
3	290.63	Series	0.1524	5.2474
4	146.88	Series	0.1524	2.6519
5	146.88	Series	0.1524	2.6519
6	46.88	Series	0.1524	0.8464
7	12.50	Series	0.1524	0.2257
Total	**781.25**			**14.1059**

Table 12.4A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.04m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	3.8442
2	15.63	Series	0.1524	0.4929
3	290.63	Series	0.1524	9.1670
4	146.88	Series	0.1524	4.6328
5	146.88	Series	0.1524	4.6328
6	46.88	Series	0.1524	1.4786
7	12.50	Series	0.1524	0.3943
Total	**781.25**			**24.6425**

Table 12.5A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.06m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	5.9393
2	15.63	Series	0.1524	0.7615
3	290.63	Series	0.1524	14.1630
4	146.88	Series	0.1524	7.1577
5	146.88	Series	0.1524	7.1577
6	46.88	Series	0.1524	2.2844
7	12.50	Series	0.1524	0.6092
Total	**781.25**			**38.0727**

Table 12.6A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.07m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	8.4855
2	15.63	Series	0.1524	1.0879
3	290.63	Series	0.1524	20.2348
4	146.88	Series	0.1524	10.2262
5	146.88	Series	0.1524	10.2262
6	46.88	Series	0.1524	3.2637
7	12.50	Series	0.1524	0.8703
Total	**781.25**			**54.3945**

Table 12.7A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.08m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	11.4827
2	15.63	Series	0.1524	1.4721
3	290.63	Series	0.1524	27.3818
4	146.88	Series	0.1524	13.8381
5	146.88	Series	0.1524	13.8381
6	46.88	Series	0.1524	4.4164
7	12.50	Series	0.1524	1.1777
Total	**781.25**			**73.6071**

Table 12.8A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.09m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	14.9307
2	15.63	Series	0.1524	1.9142
3	290.63	Series	0.1524	35.6041
4	146.88	Series	0.1524	17.9935
5	146.88	Series	0.1524	17.9935
6	46.88	Series	0.1524	5.7426
7	12.50	Series	0.1524	1.5314
Total	**781.25**			**95.7099**

Table 12.9A: Head Loss along the Pipelines from C 1101 to T 72211 at 0.10m3/s

No	Length, m	Connection	Diameter, m	Head Loss, m
1	121.88	Series	0.1524	18.8296
2	15.63	Series	0.1524	2.4141
3	290.63	Series	0.1524	44.9014
4	146.88	Series	0.1524	22.6921
5	146.88	Series	0.1524	22.6921
6	46.88	Series	0.1524	7.2422
7	12.50	Series	0.1524	1.9312
Total	**781.25**			**120.7027**

Appendix 13: Minor Head Loss for Pipelines from C 1101 to T 72211 at Different Capacity Q

Table 13.1A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.01m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	0.0398
Gate Valve	0.2000	5	0.1524	0.0189
Total				**0.0587**

Table 13.2A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.02m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	0.1590
Gate Valve	0.2000	5	0.1524	0.0757
Total				**0.2347**

Table 13.3A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.03m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	0.3578
Gate Valve	0.2000	5	0.1524	0.1704
Total				**0.5281**

Table 13.4A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.04m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	0.6360
Gate Valve	0.2000	5	0.1524	0.3029
Total				**0.9389**

Table 13.5A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.06m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	0.9938
Gate Valve	0.2000	5	0.1524	0.4732
Total				**1.4670**

Table 13.6A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.07m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	1.4311
Gate Valve	0.2000	5	0.1524	0.6815
Total				**2.1125**

Table 13.7A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.08m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	1.9478
Gate Valve	0.2000	5	0.1524	0.9275
Total				**2.8754**

Table 13.8A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.09m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	2.5441
Gate Valve	0.2000	5	0.1524	1.2115
Total				**3.7556**

Table 13.9A: Minor Head Loss along the Pipelines from C 1101 to T 72211 at 0.10m3/s

Minor Loss	K	Quantity	Diameter, m	Head Loss, m
90 deg Elbow	0.3000	7	0.1524	3.2199
Gate Valve	0.2000	5	0.1524	1.5333
Total				**4.7531**

Appendix 14: Head Loss for Pipelines from P 1112C to S 1102A/B at Different Capacity Q

Table 14.1A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.01m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	0.0356
2	3.00	Series	0.1524	0.0067
3	3.00	Series	0.1524	0.0067
Total	**22.00**			**0.0490**

Table 14.2A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.02m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	0.1324
2	3.00	Series	0.1524	0.0248
3	3.00	Series	0.1524	0.0248
Total	**22.00**			**0.1821**

Table 14.3A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.03m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	0.2889
2	3.00	Series	0.1524	0.0542
3	3.00	Series	0.1524	0.0542
Total	**22.00**			**0.3972**

Table 14.4A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.04m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	0.5047
2	3.00	Series	0.1524	0.0946
3	3.00	Series	0.1524	0.0946
Total	**22.00**			**0.6939**

Table 14.5A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.06m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	0.7797
2	3.00	Series	0.1524	0.1462
3	3.00	Series	0.1524	0.1462
Total	**22.00**			**1.0721**

Table 14.6A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.07m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	1.1140
2	3.00	Series	0.1524	0.2089
3	3.00	Series	0.1524	0.2089
Total	**22.00**			**1.5317**

Table 14.7A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.08m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	1.5075
2	3.00	Series	0.1524	0.2827
3	3.00	Series	0.1524	0.2827
Total	**22.00**			**2.0728**

Table 14.8A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.09m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	1.9601
2	3.00	Series	0.1524	0.3675
3	3.00	Series	0.1524	0.3675
Total	**22.00**			**2.6952**

Table 14.9A: Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.10m3/s

No	Length, m	Connection	Diameter, m	Head Loss
1	16.00	Series	0.1524	2.4720
2	3.00	Series	0.1524	0.4635
3	3.00	Series	0.1524	0.4635
Total	**22.00**			**3.3990**

Appendix 15: Minor Head Loss for Pipelines from P1112C to S1102A/B at Different Flow Rate

Table 15.1A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.01m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.0151
2	90 deg Elbow	0.3000	5	0.1524	0.0284
3	Gate Valve	0.2000	1	0.1524	0.0038
4	90 deg Elbow	0.3000	1	0.1524	0.0057
5	90 deg Elbow	0.3000	1	0.1524	0.0057
Total					**0.0587**

Table 15.2A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.02m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.0606
2	90 deg Elbow	0.3000	5	0.1524	0.1136
3	Gate Valve	0.2000	1	0.1524	0.0151
4	90 deg Elbow	0.3000	1	0.1524	0.0227
5	90 deg Elbow	0.3000	1	0.1524	0.0227
Total					**0.2347**

Table 15.3A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.03m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.1363
2	90 deg Elbow	0.3000	5	0.1524	0.2555
3	Gate Valve	0.2000	1	0.1524	0.0341
4	90 deg Elbow	0.3000	1	0.1524	0.0511
5	90 deg Elbow	0.3000	1	0.1524	0.0511
Total					**0.5281**

Table 15.4A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.04m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.2423
2	90 deg Elbow	0.3000	5	0.1524	0.4543
3	Gate Valve	0.2000	1	0.1524	0.0606
4	90 deg Elbow	0.3000	1	0.1524	0.0909
5	90 deg Elbow	0.3000	1	0.1524	0.0909
Total					**0.9389**

Table 15.5A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.06m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.3786
2	90 deg Elbow	0.3000	5	0.1524	0.7098
3	Gate Valve	0.2000	1	0.1524	0.0946
4	90 deg Elbow	0.3000	1	0.1524	0.1420
5	90 deg Elbow	0.3000	1	0.1524	0.1420
Total					**1.4670**

Table 15.6A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.07m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.5452
2	90 deg Elbow	0.3000	5	0.1524	1.0222
3	Gate Valve	0.2000	1	0.1524	0.1363
4	90 deg Elbow	0.3000	1	0.1524	0.2044
5	90 deg Elbow	0.3000	1	0.1524	0.2044
Total					**2.1125**

Table 15.7A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.08m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.7420
2	90 deg Elbow	0.3000	5	0.1524	1.3913
3	Gate Valve	0.2000	1	0.1524	0.1855
4	90 deg Elbow	0.3000	1	0.1524	0.2783
5	90 deg Elbow	0.3000	1	0.1524	0.2783
Total					**2.8754**

Table 15.8A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.09m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	0.9692
2	90 deg Elbow	0.3000	5	0.1524	1.8172
3	Gate Valve	0.2000	1	0.1524	0.2423
4	90 deg Elbow	0.3000	1	0.1524	0.3634
5	90 deg Elbow	0.3000	1	0.1524	0.3634
Total					**3.7556**

Table 15.9A: Minor Head Loss along the Pipelines from P 1112C to S 1102A/B at 0.10m3/s

No	Minor Loss	K	QTY	Diameter, m	Head Loss, m
1	45 deg Elbow	0.4000	2	0.1524	1.2266
2	90 deg Elbow	0.3000	5	0.1524	2.2999
3	Gate Valve	0.2000	1	0.1524	0.3067
4	90 deg Elbow	0.3000	1	0.1524	0.4600
5	90 deg Elbow	0.3000	1	0.1524	0.4600
Total					**4.7531**

Appendix 16: Minor Head Loss through Equipments at Different Flow Rate

Table 16.1A: Minor Head Loss through Equipments at 0.01m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.0095
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0000
Pump Suction	0.5000	1	0.1524	0.0095
Pump Discharge	1.0000	1	0.1016	0.0958
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.0058
Strainer Inlet	0.8000	1	0.1524	0.0151
Strainer Outlet	1.0000	1	0.1524	0.0189
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.0072
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.0023
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.0145
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.0046
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.0145
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.0046
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.0145
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.0046
Tank Inlet	1.0000	1	0.1524	0.0189
Total				**0.2404**

Table 16.2A: Minor Head Loss through Equipments at 0.02m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.0379
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0001
Pump Suction	0.5000	1	0.1524	0.0379
Pump Discharge	1.0000	1	0.1016	0.3833
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.0234
Strainer Inlet	0.8000	1	0.1524	0.0606
Strainer Outlet	1.0000	1	0.1524	0.0757
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.0290
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.0092
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.0580
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.0183
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.0580
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.0183
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.0580
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.0183
Tank Inlet	1.0000	1	0.1524	0.0757
Total				**0.9616**

Table 16.3A: Minor Head Loss through Equipments at 0.03m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.0852
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0002
Pump Suction	0.5000	1	0.1524	0.0852
Pump Discharge	1.0000	1	0.1016	0.8625
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.0526
Strainer Inlet	0.8000	1	0.1524	0.1363
Strainer Outlet	1.0000	1	0.1524	0.1704
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.0652
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.0206
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.1304
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.0413
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.1304
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.0413
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.1304
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.0413
Tank Inlet	1.0000	1	0.1524	0.1704
Total				**2.1635**

Table 16.4A: Minor Head Loss through Equipments at 0.04m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.1514
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0003
Pump Suction	0.5000	1	0.1524	0.1514
Pump Discharge	1.0000	1	0.1016	1.5333
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.0935
Strainer Inlet	0.8000	1	0.1524	0.2423
Strainer Outlet	1.0000	1	0.1524	0.3029
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.1159
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.0367
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.2319
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.0734
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.2319
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.0734
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.2319
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.0734
Tank Inlet	1.0000	1	0.1524	0.3029
Total				**3.8463**

Table 16.5A: Minor Head Loss through Equipments at 0.06m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.2366
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0004
Pump Suction	0.5000	1	0.1524	0.2366
Pump Discharge	1.0000	1	0.1016	2.3957
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.1461
Strainer Inlet	0.8000	1	0.1524	0.3786
Strainer Outlet	1.0000	1	0.1524	0.4732
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.1812
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.0573
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.3623
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.1146
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.3623
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.1146
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.3623
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.1146
Tank Inlet	1.0000	1	0.1524	0.4732
Total				**6.0098**

Table 16.6A: Minor Head Loss through Equipments at 0.07m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.3407
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0006
Pump Suction	0.5000	1	0.1524	0.3407
Pump Discharge	1.0000	1	0.1016	3.4499
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.2103
Strainer Inlet	0.8000	1	0.1524	0.5452
Strainer Outlet	1.0000	1	0.1524	0.6815
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.2609
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.0825
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.5217
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.1651
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.5217
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.1651
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.5217
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.1651
Tank Inlet	1.0000	1	0.1524	0.6815
Total				**8.6542**

Table 16.7A: Minor Head Loss through Equipments at 0.08m3/s

Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.4638
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0008
Pump Suction	0.5000	1	0.1524	0.4638
Pump Discharge	1.0000	1	0.1016	4.6956
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.2863
Strainer Inlet	0.8000	1	0.1524	0.7420
Strainer Outlet	1.0000	1	0.1524	0.9275
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.3551
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.1123
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.7101
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.2247
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.7101
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.2247
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.7101
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.2247
Tank Inlet	1.0000	1	0.1524	0.9275
Total				**11.7793**

Table 16.8A: Minor Head Loss through Equipments at 0.09m3/s

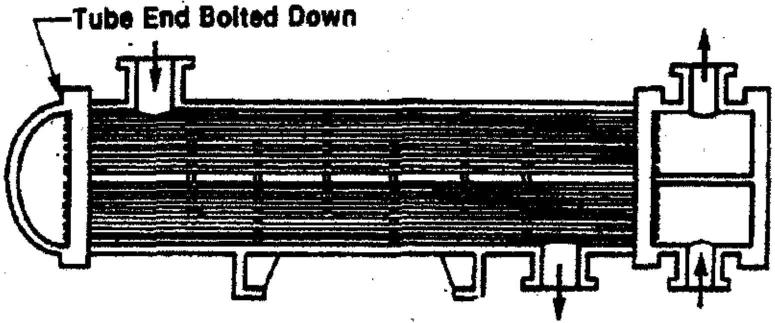
Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.6057
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0011
Pump Suction	0.5000	1	0.1524	0.6057
Pump Discharge	1.0000	1	0.1016	6.1331
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.3739
Strainer Inlet	0.8000	1	0.1524	0.9692
Strainer Outlet	1.0000	1	0.1524	1.2115
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.4638
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.1467
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	0.9275
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.2935
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	0.9275
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.2935
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	0.9275
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.2935
Tank Inlet	1.0000	1	0.1524	1.2115
Total				**15.3852**

Table 16.9A: Minor Head Loss through Equipments at 0.10m3/s

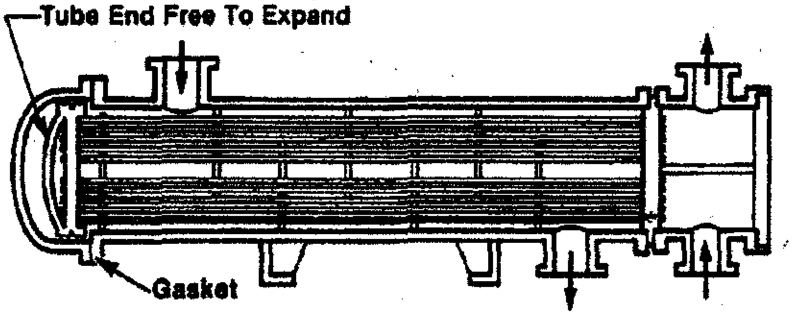
Minor Loss	K	QTY	Diameter, m	Head Loss, m
Crude Tower Outlet	0.5000	1	0.8700	0.7666
Sudden Contraction at C 1101	0.9396	1	0.87 X 0.1524	0.0014
Pump Suction	0.5000	1	0.1524	0.7666
Pump Discharge	1.0000	1	0.1016	7.7622
Sudden Contraction at P 1112C	0.3086	1	0.1524 X 0.1016	0.4732
Strainer Inlet	0.8000	1	0.1524	1.2266
Strainer Outlet	1.0000	1	0.1524	1.5333
Sudden Expansion at E 1111A/B	0.1914	2	0.1524 x 0.2032	0.5870
Sudden Contraction at E 1111A/B	0.1914	2	0.2032 x 0.1524	0.1857
Sudden Expansion at E 1108A/D	0.1914	4	0.1524 x 0.2032	1.1739
Sudden Contraction at E 1108A/D	0.1914	4	0.2032 x 0.1524	0.3714
Sudden Expansion at E 1104 A/D	0.1914	4	0.1524 x 0.2032	1.1739
Sudden Contraction at E 1104A/D	0.1914	4	0.2032 x 0.1524	0.3714
Sudden Expansion at E 1127A/D	0.1914	4	0.1524 x 0.2032	1.1739
Sudden Contraction at E 1127A/D	0.1914	4	0.2032 x 0.1524	0.3714
Tank Inlet	1.0000	1	0.1524	1.5333
Total				**19.4719**

Appendix 17: Types of Shell and Tube Heat Exchanger (refer from Area 1 CDU Heat Exchanger)

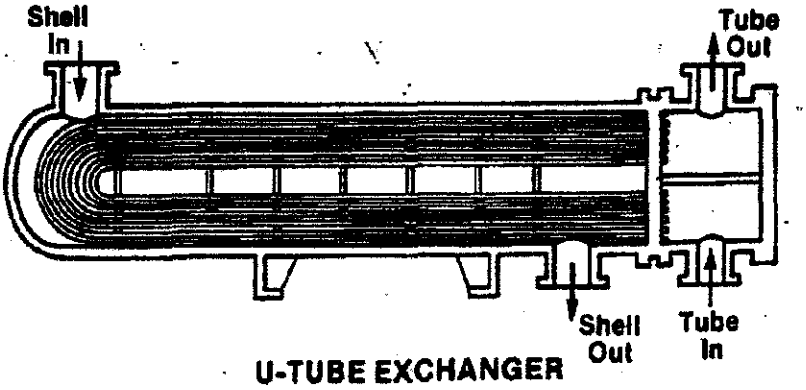
SHELL AND TUBE HEAT EXCHANGERS



FIXED TUBE SHEET EXCHANGER



FLOATING HEAD TYPE EXCHANGER



U-TUBE EXCHANGER

12-7

Appendix 18: TNB's Tariff

Tariff D - Low Voltage Industrial Tariff
For Overall Monthly Consumption Between 0-200 kWh/month
For all kWh (sen/kWh) 32.5
The minimum monthly charge is RM7.20
For Overall Monthly Consumption More Than 200 kWh/month
For all kWh (From 1kWh onwards) (sen/kWh) 34.8
The minimum monthly charge is RM7.20
Tariff Ds – Special Industrial Tariff (for consumers who qualify only)
For all kWh (sen/kWh) 32.7
The minimum monthly charge is RM7.20

Tariff E1 - Medium Voltage General Industrial Tariff
For each kilowatt of maximum demand per month RM/kW 23.40
For all kWh (sen/kWh) 26.6
The minimum monthly charge is RM600.00
Tariff E1s – Special Industrial Tariff (for consumers who qualify only)
For each kilowatt of maximum demand per month RM/kW 18.10
For all kWh (sen/kWh) 25.8
The minimum monthly charge is RM600.00

Tariff E2 - Medium Voltage Peak/Off-Peak Industrial Tariff
For each kilowatt of maximum demand per month during the peak period RM/kW29.30
For all kWh during the peak period (sen/kWh) 28.1
For all kWh during the off-peak period (sen/kWh) 17.3
The minimum monthly charge is RM600.00
Tariff E2s – Special Industrial Tariff (for consumers who qualify only)
For each kilowatt of maximum demand per month during the peak period RM/kW25.20
For all kWh during the peak period (sen/kWh) 25.8
For all kWh during the off-peak period (sen/kWh) 14.7
The minimum monthly charge is RM600.00

Tariff E3 - High Voltage Peak/Off-Peak Industrial Tariff
For each kilowatt of maximum demand per month during the peak period RM/kW28.10
For all kWh during the peak period (sen/kWh) 26.6
For all kWh during the off-peak period (sen/kWh) 16.0
The minimum monthly charge is RM600.00
Tariff E3s – Special Industrial Tariff (for consumers who qualify only)
For each kilowatt of maximum demand per month during the peak period RM/kW22.20
For all kWh during the peak period (sen/kWh) 24.3
For all kWh during the off-peak period (sen/kWh) 13.4
The minimum monthly charge is RM600.00

Appendix 19: Graph of Effectiveness versus NTU [22]

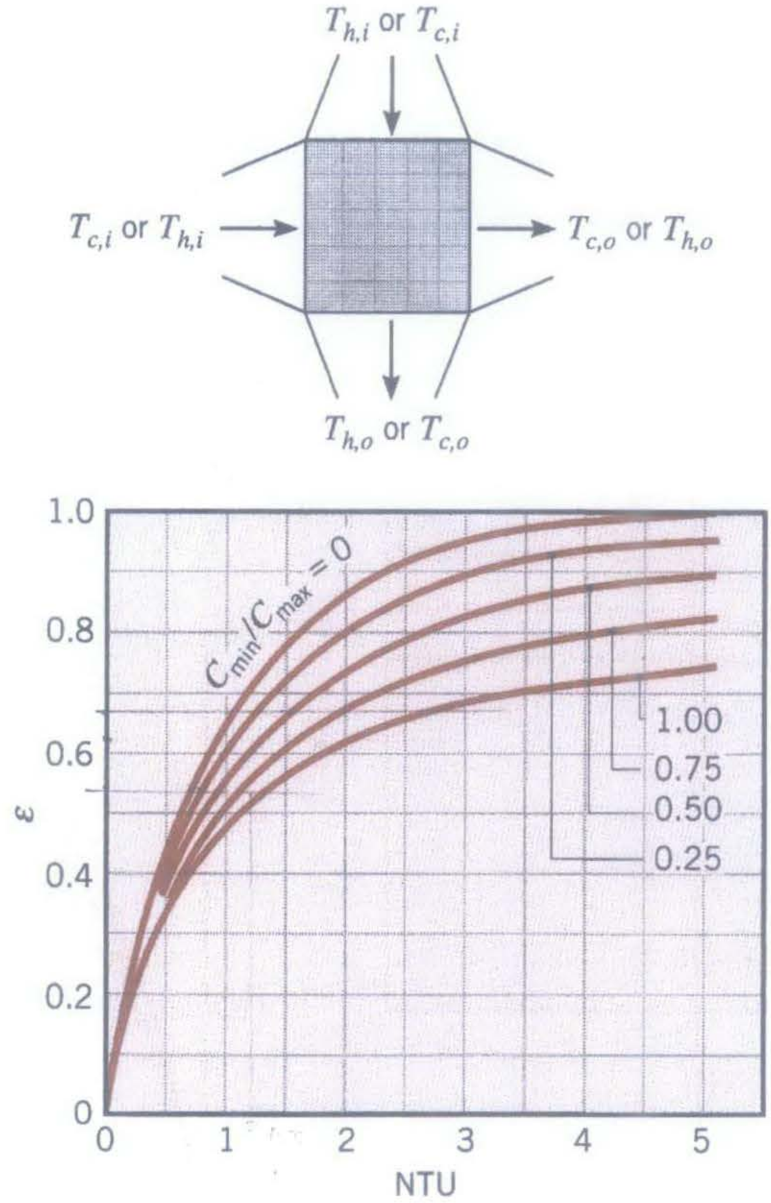


FIGURE 11.14 Effectiveness of a single-pass, cross-flow heat exchanger with both fluids unmixed (Equation 11.32).