CERTIFICATION OF APPROVAL

Feasibility Study on the Replacement of Traditional Heat Exchanger by ALFA LAVAL COMPABLOC in PETRONAS OPUs.

by

Sebastian anak Sidi

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

Approved by,

____

(AP Dr Hussain Al-Kayiem)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

October 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.

SEBASTIAN ANAK SIDI

ABSTRACT

Selection of a heat exchanger for a certain application is a considerable decision making. The performance of the selected heat exchanger should meet the maximum demand of the operation unit involving the heat exchanger and also the cost factor is of high importance since it consist the maintenance and the running cost.

In the present work, analysis had been carried out to investigate the possibility of replacing existing traditional heat exchanger with compact types. The study is based on the performance analysis to meet the operational requirement of PETRONAS OPU. Also a cost analysis has been conducted to compare between the traditional and the compact heat exchanger.

The results obtained have shown that COMPABLOC require less heat transfer area than the STHE at the same thermal duty. On the cost analysis part, the analysis reveals that the replacement is feasible and justified.

ACKNOWLEDGEMENTS

First of all, I would like to express my utmost gratitude and appreciation to God Almighty because with His blessings and help, my Final Year Project went very smoothly for me and I am able to complete the project in time.

My special thanks go to my supervisor, AP. Dr Hussain Al-Kayiem for his guidance. Without his help and guidance I will not be able to proceed with this project and also would not have any idea on how to approach this project. I would also like to thank AP Dr. Hussain for giving me his opportunity and believing that I can contribute and work for this project.

I also would like to thank Petronas Penapisan Melaka engineers, especially Ir Azakri Ekhwan and Mr. Khairul Irman b. Dollmat for the information that they provided for me. And not to forget, the ALFA LAVAL staff, especially Mr. Sani Zulkiepli, Mr Roslan Hassan, Mr Daniel Ng., Mr Nai Siang Ling and Miss Evae Andersson who have been helping me with their expertise in COMPABLOC and also for their kindness to let me use their software.

Last but not least, I would like to thank my family and friends for always supporting me throughout the completion of this project. Thank you very much to everyone.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Shell and tube heat exchanger has been used for quite some time. This type of heat exchanger is easily recognized with its bulky size, long and consists of shell and tube, with baffles to direct its flow. The advantage of the shell and tube heat exchanger is its ability to withstand heavy duty process. However as the technology advances, other types of heat exchanger emerge and offer much better options to the company that uses the heat exchanger and one of them is the compact plate heat exchanger.

Compact plate heat exchanger has been used widely around the world. A few models ranging from the gasketed plate heat exchanger to the latest model which is the spiral heat exchanger has been produced recently. This type of heat exchanger offers a much better performance, with a better overall heat transfer rate. Besides that, the compact heat exchanger also offers other advantages, such as versatility, small size, easy maintenance procedure and also the self cleaning effect.

Alfa Laval is one of the providers of heat exchanger. This company which based in Sweden has been producing different kinds of heat exchanger. One of them is COMPABLOC, a compact heat exchanger that is welded, with cross flow corrugated plate. This type of heat exchanger has been proven to be much more effective than the shell and tube heat exchanger, due to its corrugated plate

Recently a lot of companies started to do research and also conducted feasibility study on the replacement of the shell and tube heat exchanger to compact heat exchanger. A few parameters of the heat exchanger are compared to justify this decision to execute the replacement process. Besides doing analytical analysis on the performance of the heat exchanger, the cost analysis is also being conducted. This is to look at the feasibility of changing the old equipment to new equipment. This research will be the base of my project in conducting the feasibility study on the replacement of the traditional heat exchanger to the COMPABLOC.

1.2 Basic of Heat Exchanger

According to Ramesh K. Shah [1], a heat exchanger is a device that transfers internal thermal energy between two or more fluid, between solid surface and fluid or between solid particulates and fluid. Typical application of heat exchanger are heating and cooling of fluid stream, evaporation or condensation of single or multicomponent fluid stream and heat recovery or heat rejection from a system. The method of transferring heat might differ, some heat exchanger transfer heat of fluid in direct contact, through a separating wall or into and out of the wall in a transient manner. Most of the heat exchanger separate the fluid by a heat transfer surface and do not mix. This type of heat exchanger is referred to as direct transfer type or recuperators. For exchanger where there is an intermittent flow of heat from the hot to cold fluid are referred to as indirect transfer type or regenerators.

Heat transfer surface is the essential part of the heat exchanger which is in direct contact with the fluids and through which the heat is transferred by conduction in a recuperator. The portion of the surface which separates the fluid is referred to as primary or direct surface. To increase heat transfer area, appendages known as the fin may be connected to the primary surface to provide an extended, secondary or known as indirect surface. The addition of the fin reduces the thermal resistance on the side and thus increases the heat transfer from the surface for the same temperature difference.

Heat exchanger is classified according to transfer process, construction, flow arrangement, surface compactness, number of fluids and heat transfer mechanism. This can be shown by figure 1.1:

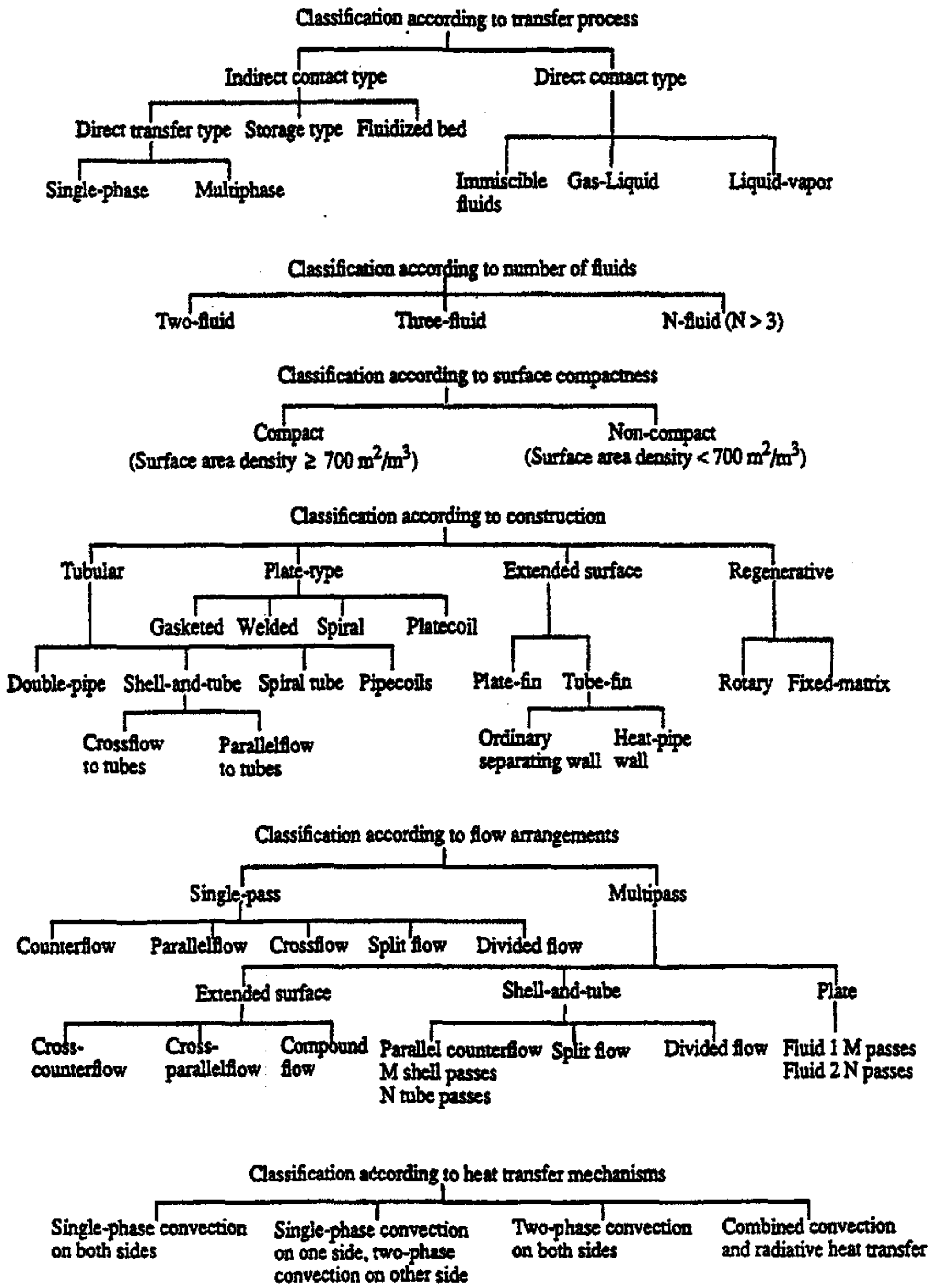
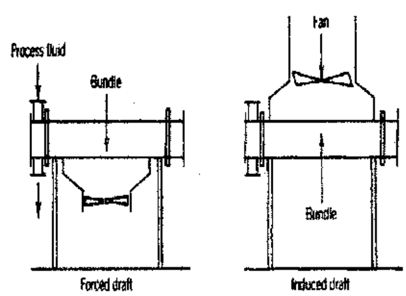


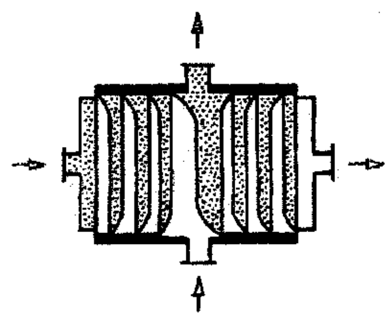
Figure 1.1: Classification of Heat Exchanger [1]

A gas to liquid heat exchanger is referred to as compact heat exchanger if it incorporates a heat transfer surface having a surface area density above about 700 m^2/m^3 on at least one of the fluid sides which usually has gas flow. It is referred to as a laminar flow heat exchanger if the surface area density is above about 3000 m^2/m^3

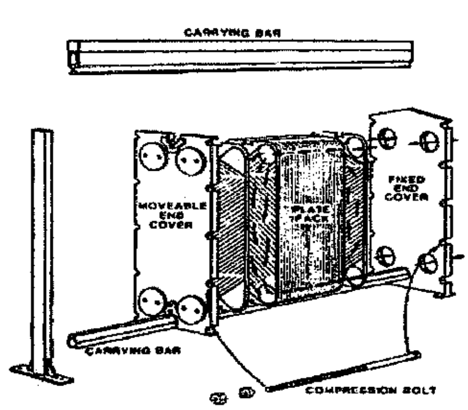
and as a micro heat exchanger if the surface area density is above about 10 000 m^2/m^3. A liquid two phase heat exchanger is referred as a compact heat exchanger if the surface area density on any one fluid side is above 400 m^2/m^3. The shell and tube heat exchanger has surface area density of less than 100 m^2/m^3 on one side fluid side with plain tubes and two to three times that with the high fin density low finned tubing. Plate fin, tube fin and rotary generator are example of compact heat exchanger for gas flows on one or both fluid sides and gasketed and welded plate heat exchanger are example of compact heat exchanger for liquid flows. Figure 1.2 shows different type of heat exchanger widely used in industry:



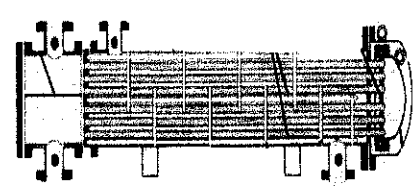
(a) Air Cooled Heat Exchanger



(c) Spiral Heat Exchanger



The Plate Heat Exchanger



(d) Tube and Shell Heat Exchanger

Figure 1.2: Examples of Heat Exchanger Used in the Industries [1]

1.3 Alfa Laval Background

According to report in [2], Alfa Laval is founded by Dr Gustav de Laval and Oscar Lamm. Their first product was the centrifuge used to separate milk and cream. As the technology advances, they stated to invent milk pasteurizer and the development of heat exchanger to ensure pasteurization process. Today, Alfa Laval which is listed on the Swedish stock market is a group of businesses that specializes in heat exchange, separation, and flow transfer. Their product is used to heat, cool, separate and transport products in industries that produce foods and beverages, chemicals and petrochemicals, pharmaceuticals, starch, sugar and biofuels. Alfa Laval's products are also installed on oil platforms, in power plants, aboard ships, in the mechanical engineering industry, in the mining industry and for wastewater treatment, as well as for comfort climate and refrigeration applications [2].Below is an example of a few industries that has been using Alfa Laval products:

a) Beverages
b) Biofuels
c) Biotech and pharmaceutical
d) Chemicals
e) Food
f) HVAC
g) Machinery
h) Marine and diesel power
i) Metal and mineral extraction
j) Metal working
k) Oil and gas
l) Oil refinery
m) Power
n) Refrigeration and cooling

Alfa Laval is fast becoming the global leader in engineering with efficient and reliable processing equipment that they supply to the industries above. The advancement in term of their heat exchanger is quite impressive, as they started to invent the plate heat exchanger in 1931, and up to now, they have a lot of series, mainly AlfaRex, Vicarb, Packinox, Spiral and also the Compabloc. Figure 1.3 shows a few example of Alfa Laval heat exchanger product:

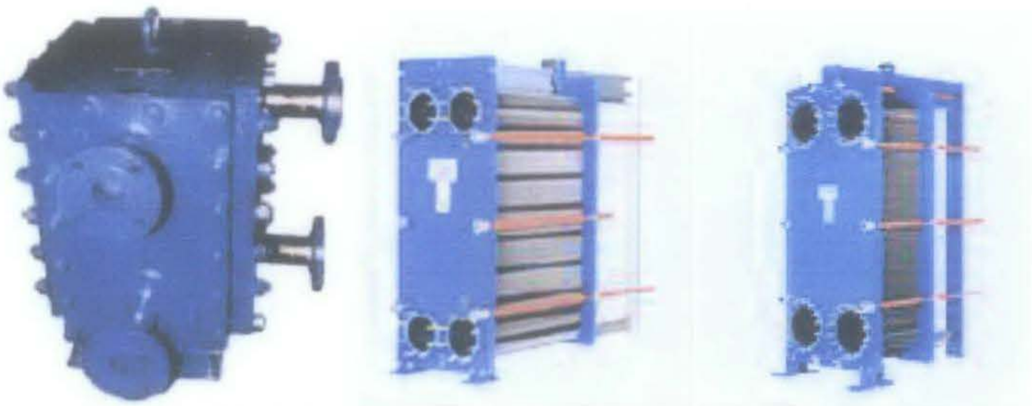


Figure 1.3: The welded plate heat exchanger COMPABLOC, the gasketed T-series and the M-series (from left to right) [3]

1.4 Problem Statement

Shell and tube heat exchanger has been used quite extensively around PETRONAS OPUs. The problem with STHE is that the maintenance cost is very high. This is due to the STHE big size, which consume a lot of time for maintenance and requires thorough cleaning during maintenance.

1.5 Objectives

1) To conduct mathematical analysis on the viability of replacement of the traditional heat exchanger by proposed COMPABLOC.
2) To carry out cost analysis

1.6 Scope of Study

Is it beneficial for PETRONAS OPUs to replace the traditional heat exchanger by the COMPABLOC? The research will focus on finding the thermophysical properties of the heat exchanger such as the mass flow rate, the heat exchanged, the pressure drop and a few other properties which is essential for a heat exchanger. This calculation will be compared to justify ALFA LAVAL claims. Besides that, for the cost analysis part, the maintenance cost, the capital cost and a few additional costs will be used in the replacement cost analysis to justify the replacement process.

1.7 Significance of Study

The research will be able to help PETRONAS OPU's in determining the properties of the heat exchanger and also to provide justification especially on the cost of replacing the traditional heat exchanger. Besides that, they will learn more details on the heat properties of the COMPABLOC and its specification before buying the COMPABLOC. By justifying the replacement of the heat exchanger, this will help PETRONAS to make the decision easier and they would be able to use this thesis as their guidelines in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Shell and Tube Heat Exchanger (STHE)

According to Kenneth J. Bell [1], shell and tube heat exchanger has been widely used in industries for various purposes, ranging from condenser, evaporator and many more. They are designed for virtually any capacity and operating condition, from high vacuum to high pressures, from cryogenics to high temperatures and for any temperature and pressure differences between the fluids. Besides that, the SHTE is designed for special operating conditions: vibration, heavy fouling, highly viscous fluid, erosion, corrosion and multicomponent mixtures. They are made from variety of metal and non metal materials and in surface areas from less than 0.1 to 100000 m^2. The SHTE is consisted of a bundle of tubes enclosed in a shell and so arranged that one fluid flows through the tubes and another fluid flows across the outside of the tubes. The heat is being transferred through the tube wall. Other mechanical components are required to guide the fluid into, through and out of the exchanger, preventing the fluid mixing and to ensure the mechanical integrity of the heat exchanger. A typical SHTE is shown in figure 2.1:

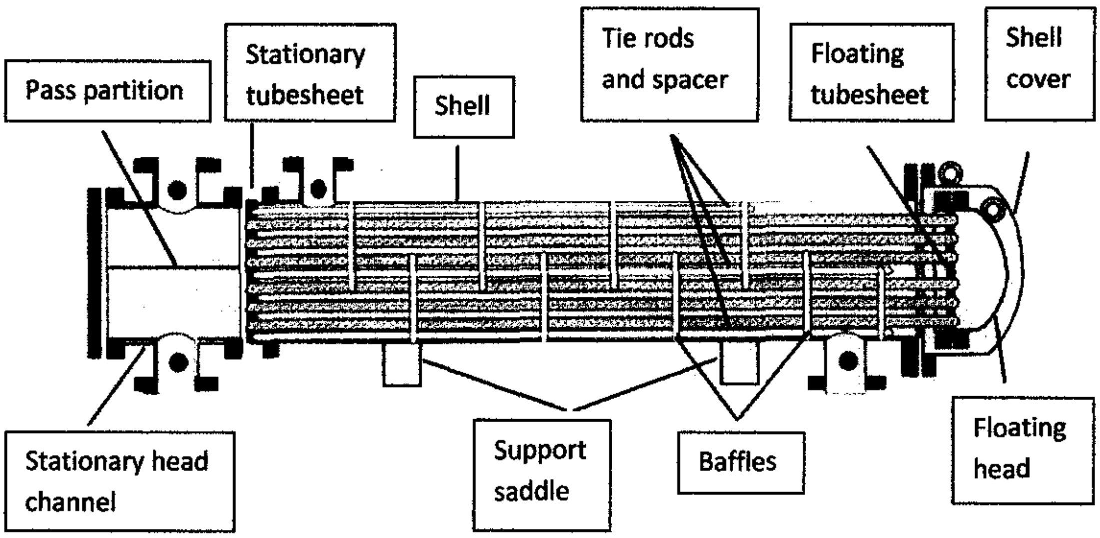


Figure 2.1: Configuration of a STHE (Floating head) [1]

The tube and shell heat exchanger has several problems that have been highlighted lately. One of the problems is the size of the shell and tube heat exchanger, which consume a lot of space. Its horizontal configuration and cylindrical shape requires a lot of space and the company also have to take account the space for the maintenance of the STHE, since it requires the tube bundles to be pulled out.

From the Alfa Laval research produced by Eva Andersson [3], the maintenance cost of the SHTE is also very high, due to the needs to dismantle the SHTE parts. Besides that, the maintenance requires a lot of man power, effort and consumes a lot of time. The maintenance process can take up to 1 week and this will cost a lot, in term of labor charge and loaning of maintenance tools. The SHTE had to be cleaned once per year and also be opened for annual inspection as stipulated by the local safety authority. This increases downtime period and thus affect the productivity of a company. In term of low heat recovery problem, the SHTE is modified by making the tubes longer, arranging the tubes with many passes and connecting the several tubes in series. This modification causes hydraulics problem due to the reduced channel of velocity through the large units. The hydraulic problem lowers the thermal efficiency of the SHTE and also increases the fouling problem.

2.2 Compact Plate Heat Exchanger (CPHE)

A CPHE, as defined by Ramesh K. Shah [1], is a heat exchanger which is consisted of thin plate, stacked alternately to produce counter flow. This plate is usually made of stainless steel and also titanium to avoid the effect of corrosive material. The media is separated by gasketed plate or welded plate.

Based on the report by Alfa Laval [4], the COMPABLOC of Alfa Laval is an all welded compact heat exchanger which has a high efficiency. The CPHE is designed to handle aggressive and hazardous process services. The heat transfer area is ranging from 0.7 to 850 m^2. The CPHE is consisted of a pack of corrugated plates made of stainless steel or other high alloy metals and alternately welded to form channels. These channels direct the flow of the media inside the CPHE, besides avoiding the media to mix up. The corrugated plates which are stacked force the media to "spiral" its way into the channel, therefore creating a high level turbulence. As a comparison with the STHE, at same velocity, a CPHE achieve greater turbulence and give thermal efficiency which is 3-5 times greater than the STHE. The high turbulences created also creating a high shear wall stress that has a cleaning effect which will reduce the fouling inside the CPHE. This will allow the CPHE to operate for longer intervals without maintenance. The figure below shows the corrugated plate of COMPABLOC:

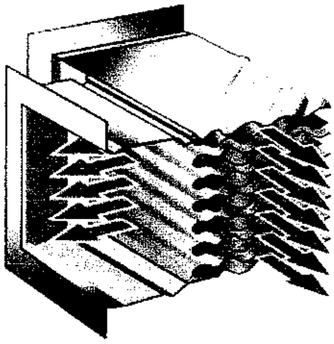


Figure 2.2: Corrugated Plates and Its Flow Direction [4]

The corrugated plate is supported by an upper and lower head and four side panel for connection purposes. The side panel eases the maintenance procedure of the CPHE. The baffle directs the flow of the media to form an alternate flow. CPHE require small space for its base as even the largest CPHE with the heat transfer surface of 850 m^2 needs 15 m^2 areas. Figure 2.3 shows the configuration of a CPHE.

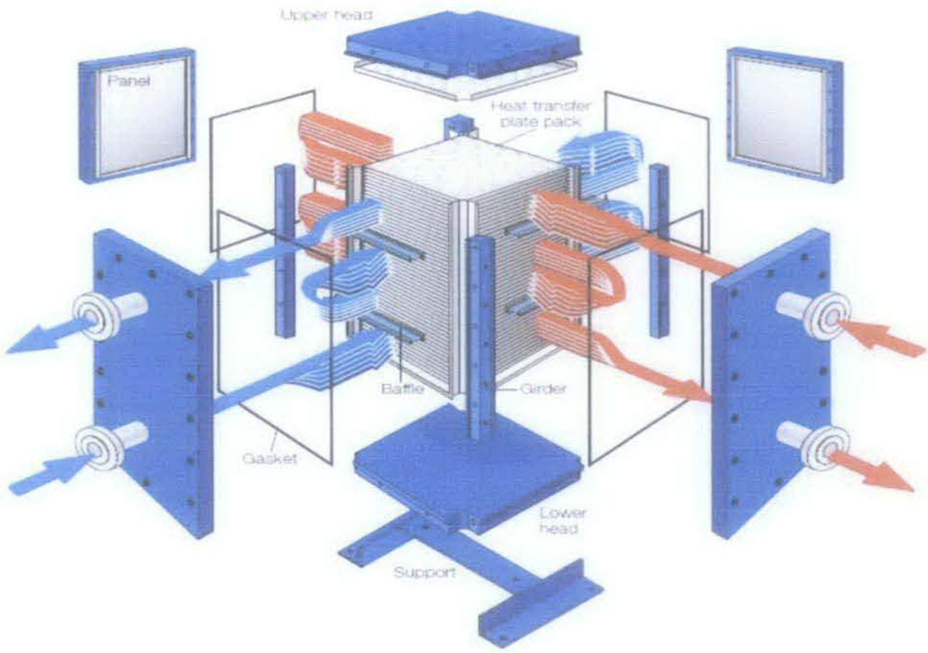


Figure 2.3: Configuration of COMPABLOC [4]

2.3 Case Studies on the Replacement of Traditional STHE to COMPABLOC

2.3.1 Nynas Refinery Case Study

A few case studies conducted by Alfa Laval on the replacement of STHE to COMPABLOC will be explained in this part. The first study is on the Nynas Refinery in Gothenburg Sweden. According to Alfa Laval [5], they are the main producer of bitumen in Sweden. To date they have installed 11 COMPABLOCs at the plant mainly for cooling of kerosene and gas oil in atmospheric distillation. The COMPABLOCs are designed with corrosion resistant material such as stainless steel and titanium. Originally they use traditional STHE which are large, heavy and service demanding.

One of the advantages of COMPABLOC is its size. They installed a few units at a high level where space is at premium. The installation of one COMPABLOC required only 1/3 (horizontal mounted COMPABLOC) or 1/6 (vertically mounted COMPABLOC) of the space the STHE occupied. In term of cost saving, they managed to reduce the time on HE downtime. COMPABLOC is cleaned once in 3 years, by either hydro jetting or by using Cleaning in Place (CIP) method. COMPABLOC also have low fouling tendency due to its high shear rates along the heat wall.

After the change, Nynas Refinery managed to decreased service downtime period from 3 weeks to 1 day. This contributed to a reduction of service cost from EURO 25 000 to less than EURO 1000 per exchanger.

2.3.2 Syzran Oil Refinery

The Syzran Oil Refinery is run by YUKOS Oil Company in Russia. The plant has the capacity of 150 000 barrel of crude oil per day. The COMPABLOC is installed at the plant when the expansion of the plant is done. Based on their research [6], after the installation of COMPABLOC they manage to reduce the downtime significantly, as the inspection and cleaning of the units are seldom required.

The COMPABLOC shows its versatility as shown in the figure 2.4:

(a) (b)

Figure 2.4: (a) Compabloc reflux condenser mounted directly on the column. (b) Compbloc reboilers operating with steam as heating medium. [6]

The direct installation on figure 2.4 (a) saves cost as the connection, foundation installation, piping and pump cost is being reduced.

2.3.3 Tamoil Plant in Callombey, Switzerland

Based on the report written by Alfa Laval [7], in 1995, Tamoil was planning to recover energy from the atmospheric-distillation-tower overhead vapour as an action to improve the heat recovery in its refinery. But one main constraint is that the installation would be done at the top of the tower. Due to this space constraint, Tamoil decided to go for COMPABLOC. The nature of the process, which could cause corrosion due to the presence of chlorides in the virgin naphtha also prompt Tamoil to use titanium plates to avoid corrosion. According to the report, Tamoil used only 30m^2 of area for 4 COMPABLOC in Titanium, and this is inclusive of the service area. Besides saving space, Tamoil also able to recover 16.5 MW of energy annually, which they used to preheat crude and boiler feed water. Table 2.1 shows the annual savings and also the payback period of the replacement:

Table 2.1: Calculated Payback Time [7]

Compabloc purchase cost	EUR 1.4 million
Installation cost	EUR 1.4 million
Annual fuel savings	EUR 3.8 million
Annual emission savings	EUR 1.0 million
Payback time	7 months

Another case study conducted by ALFA LAVAL [3] comparing the heat recovery of STHE and COMPABLOC. The table below shows the comparison:

Table 2.2: Comparison between COMPABLOC and STHE, showing the difference in shear stress and heat transfer surface for heat recovery duties featuring medium and high NTU values. [3]

	Diesel / crude HX Diesel 173- 88^{0}C NTU=2.00 Crude 70 – 89^{0}C NTU=0.45		Diesel stripper feed/bottom HX Bottom 251- 83^{0}C NTU=6.0 Crude 215 – 62^{0}C NTU=5.5	
	COMPABLOC	STHE	COMPABLOC	STHE
Number of heat exchanger	1	1	3	4
Number of passes	11/4(hot/cold side)	4/1(tube/shell)	16/16	4/1
Pressure drop, kPa	85/115	60/82	90/120	90/115

Shear, Pa	31/112	4	16/21	3.2
Total HTA (m2)	70	400	770	3344

The NTU is the thermal length of the HE, calculated using the equation:

$$NTU = \theta = \frac{T_1 - T_2}{MTD}$$

Where T_1: Inlet temperature

T_2: Outlet temperature

MTD: Mean Temperature Difference

The MTD acts as a driving force for heat transfer inside the HE. The larger the MTD the easier the heat transfer. The NTU is the value of the effort needed to carry out a certain heat transfer duty [3].

Based on the table, we can see clearly even with a lesser heat transfer area, COMPABLOC has higher shear stress and pressure drop inside the HE. Both of these properties are important in heat recovery. The Alfa Laval Packinox also makes a summary of comparison between COMPABLOC and STHE and is shown in the table below:

Table 2.3 Comparison Table between COMPABLOC and STHE [3]

Properties	COMPABLOC	STHE
Wall Shear Stress	5-8	1
Heat Transfer Efficiency	3-5	1
Heat Transfer Area	1	3 – 5
Pressure Drop	1.2-1.5	1
Service Area	1	4 – 10
Weight Empty	1	1.5 – 4
Weight Full	1	2 – 5
Installation Cost	1	1.5 – 2
Hold Up Volume	1	30 – 40

The values inside the table represent the factor of how much the properties of one HE higher than the other HE.

2.4 Optimization of Heat Exchanger

According to Webb [8] on general optimization methods gave several considerations for design optimization. The goal of optimization must first be established: it could be for size reduction of the heat exchanger and/or to reduce operating costs. The operational variables that could be optimized are the heat transfer rate, pumping power (pressure drop), flow rate and fluid velocity. When considering optimization by reducing its size, the increase in manufacturing cost should be taken into account.

2.5 Flow and Heat Transfer Mechanism

According to Bengt Sunden [8] the investigation of flow field in CPHE has been carried out only to a limited extend due to the complex geometry and narrow passage of the plate. The turbulence in the corrugated plate is promoted by the continuously change in flow direction and velocity. The created channel promotes a swirling motion of the fluid.

2.6 Numerical Investigations of Flow and Thermal Field

In the journal by Ciofalo et al [8] they found out that the standard k-ε model with wall functions gave acceptable results at high Reynolds number but failed at lower values of Re. the laminar flow result were acceptable at low Re number and for moderate angles between the plates.

Mehrabian et al [8] also conduct a numerical investigation with three different corrugation inclination angles. Only laminar cases were considered in his approach. The calculated frictions factor was much higher than the corresponding experimental values.

The RNG k-ε as stated by Bengt Sunden [8] is the basic idea of the Re-Normalization Group (RNG) in turbulent flow is to systematically remove the small scales of turbulence to a point where large scales of turbulence are resolvable. The mathematical derivation is developed by Yakhot et al [8] in their journal.

CHAPTER 3

METHODOLOGY

The methodology of this research is mainly to conduct the mathematical analysis and cost analysis on the replacement of the STHE by COMPABLOC. The collaboration with THERMATEK and PETRONAS PENAPISAN Melaka will provide the data required to do mathematical analysis.

3.1 Collaboration with THERMATEK

THERMATEK is a company that distribute ALFA LAVAL product in Malaysia. The information on the COMPABLOC will be collected from this company to assist in the research.

3.2 Collaboration with PETRONAS PENAPISAN Melaka.

Raw data of the shell and tube heat exchanger is collected from the company. This data will be used to compare the performance and the cost of the heat exchanger.

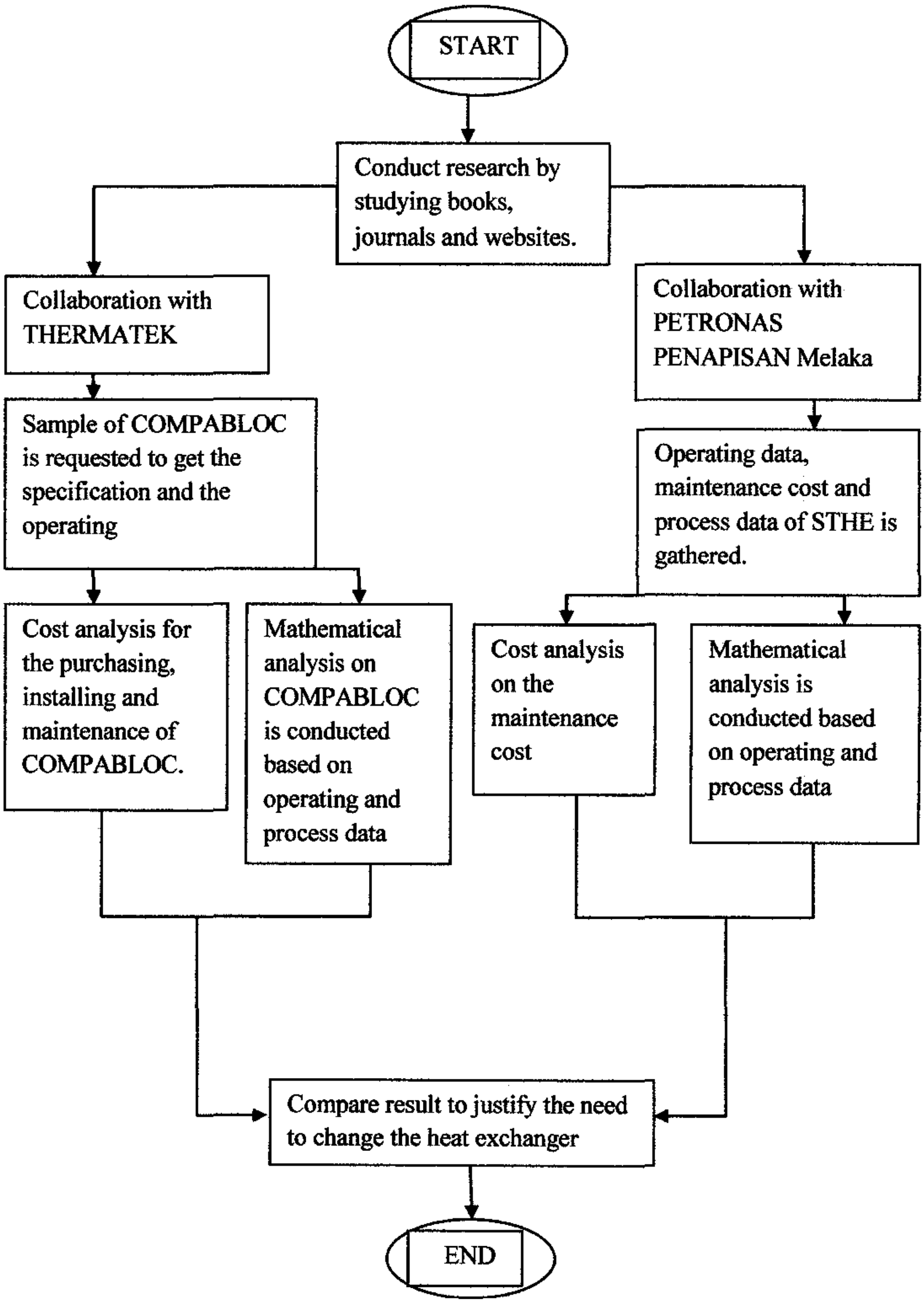
3.3 Analytical Analysis

For the analytical analysis part, a few of the properties of the heat exchanger will be calculated and compared.

3.4 Cost Analysis

The basic tool to carry out the cost analysis is by using the cost/benefit analysis.. If the cost or benefit are paid or received over time, work out the time it will take for the benefit to repay the cost.

3.5 Execution Flow Chart



3.5 Gantt Chart

CHAPTER 4

ANALYSIS

For analysis part, in the analytical analysis part, the properties of the heat exchanger, such as the mass flow rate, the heat transfer area and the pressure drop will be calculated. In the cost analysis part, the maintenance cost and the replacement cost analysis will be conducted.

4.1 Analytical Analysis

The data gathered is the heat exchanger design data from PETRONAS PENAPISAN MELAKA.

Table 4.1: Heat Exchanger Fluids' Properties

	Shell side	Tube side
Fluid	Low sulphur waxy residue	WATER
Inlet, °C	131	66
Outlet, °C	79	79
Fluid Density, kg/m3	875	1000
Cp (AVERAGE), Kj/KG.k	1.67	4.191
Thermal conductivity (in) W/m.k	0.134	0.660
Thermal conductivity (out) W/m.K	0.139	0.668
Viscosity (in) N.s/m2	0.00874	0.00042
Viscosity (out) N.s/m2	0.0353	0.000365

The calculation of the heat properties of the exchanger is as follows:

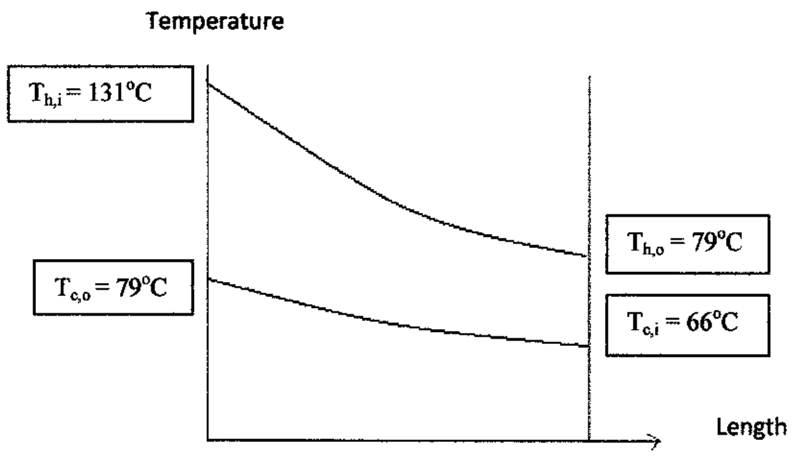


Figure 4.1 Temperature diagram

For both heat exchangers, the following assumption is made:

1) 1 pass heat exchanger
2) Both HE have the same overall heat transfer rate, q.

The overall heat transfer rate, $q = \dot{m}c\Delta T_h$ (1)

Where:

$\dot{m}: mass\ flow\ rate\ of\ water$

$c: specific\ heat\ of\ water$

$T_h: water\ temperature$

$$q = 75\frac{kg}{s} \times 4.191\frac{kJ}{kg.K} \times (79 - 66)K$$

$$q = 4086.2\ kW$$

Log Mean Temperature Difference, ΔT_m :

$$\Delta T_m = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{ln\frac{(T_{h,i} - T_{c,o})}{(T_{h,o} - T_{c,i})}} \quad (2)$$

$$= \frac{(131-79)-(79-66)}{In\frac{(131-79)}{(79-66)}} = 28.1\,°C$$

4.1.1 The Mass Flow Rate inside HEX:

a. Mass flow rate in single tube:

$$\dot{m} = \frac{inlet\ mass\ flow\ rate}{number\ of\ tubes\ per\ pass} \quad (3)$$

$$= \frac{75kg/s}{270\ tubes}$$

$$= 0.27\ \frac{kg}{s}$$

b. The mass flow rate per pass in COMPABLOC [appendix 2]:

$$\dot{m} = \frac{inlet\ mass\ flow\ rate}{number\ of\ passage\ per\ pass} \quad (4)$$

$$= \frac{75kg/s}{\frac{151plates}{5pass}}$$

The number of plates and the number of pass are determined by CAS software [appendix 2].

$$= 2.48\ \frac{kg}{s}$$

4.1.2 The Calculation of Reynolds Number

The Reynolds number for the STHE is calculated as follows:

$$Re_D = \frac{4.\dot{m}}{\pi.D.\mu} \quad (5)$$

$D = diameter\ of\ tube$

µ̃ = 0.00039 [9]

$$= \frac{4 \times 0.27 \frac{kg}{s}}{\pi \times 0.01483m \times 0.00039 \frac{kg}{m.s}}$$

$= 59\ 438$

For flow inside a tube, if the Reynolds number is more than 2000, the flow is a turbulent flow. [10]

4.1.3 Heat Transfer Area

The heat transfer area, A is calculated from the equation provided in [9]. The equation is as follows:

$$q = UA\Delta T \tag{6}$$

The q is calculated in section 4.1.1 and the value is 4086.2 kW. The ΔT also calculated in section 4.1.2 and the value is 28.1°C. To calculate U, the following equation is used:

$$U = \frac{1}{h_i} + \frac{1}{h_o} + \frac{\delta}{\lambda} \tag{7}$$

$U: Overall\ heat\ transfer\ coefficient$
$h_i: heat\ tranfer\ coefficient\ tube\ side, W/m^{2o}C$
$h_o: heat\ transfer\ coefficient\ in\ shell\ side, W/m^{2o}C$
$\delta: wall\ thickness = 0.001\ m$
$\lambda: wall\ conductivity = 18.5\ W/mC$

For h_i, the heat coefficient is calculated as follows:

$$h_i = Nu\frac{k}{D} \tag{8}$$

$k = \frac{0.664W}{m^{2o}C}\ (table\ A6\ [5])$
$D: tube\ diameter = 0.01483\ m[appendix\ 1]$

$$Nu = 0.023Re^{\frac{4}{5}}Pr^{0.4} \tag{9}$$

$Re = 59438\ (section\ 4.1.2)$

$Pr = 2.45\ (table\ 6\ [5])$

$$Nu = 0.023(59438)^{\frac{4}{5}}(2.45)^{0.4}$$
$$= 217$$

$$h_i = 217\frac{0.664}{0.01483}$$
$$= 9720\ W/m^{2o}C$$

For h_o, the heat transfer coefficient is calculated based on the Donohue equation as follow:

$$\frac{h_oD_o}{k} = 0.2\left(\frac{DoGe}{\mu}\right)^{0.6}\left(\frac{cp\mu}{k}\right)^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{10}$$

This equation is to calculate the property of the shell side of the SHTE. The following is the parameter needed and given by PPM.

$f_b: fraction\ of\ cross\ sectional\ area\ of\ shell\ occupied\ by\ baffle\ wind$
$= 0.1955m$

$Ds: inside\ diameter\ of\ shell = 1.17m$

$N_{bt}: number\ of\ tubesin\ baffle\ window = 53$

$P_b: baffle\ pitch = 0.259m$

$p_t: tube\ pitch = 0.0254m$

$d_o: outside\ diameter\ of\ tube = 0.01905m$

Calculate the mass velocity as follows:

$$G_b = \frac{\dot{m}(shell)}{\frac{\pi}{4}\left(f_bDs^2 - N_{bt}{d_o}^2\right)} \tag{11}$$

$$G_b = \frac{\frac{47kg}{s}}{\frac{\pi}{4}(0.1955m \times 1.17m^2 - 53m \times 0.01905m^2)}$$
$$= 241\ kg/s.m^2$$

$$G_c = \frac{\dot{m}(shell)}{P_b D_s \left(1 - \frac{d_o}{p_t}\right)} \tag{12}$$

$$= \frac{47kg/s}{0.259m \times 1.17m \left(1 - \frac{0.01905}{0.0254}\right)}$$

$$= 620\ kg/s.m^2$$

The property below is extracted and estimated from appendix 1:

$\mu = 0.02202$

$cp = 1.67$

$k = 0.137$

$\mu_w = 0.0003925$

$$\frac{h_o d_o}{k} = 0.2\left(\frac{DoGe}{\mu}\right)^{0.6}\left(\frac{cp\mu}{k}\right)^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{13}$$

$$\frac{h_o \times d_o}{k}$$

$$= 0.2\left(\frac{0.01905 \times \sqrt{241 \times 620}}{0.02202}\right)^{0.6}\left(\frac{1.67 \times 0.02202}{0.137}\right)^{0.33}\left(\frac{0.02202}{0.0003925}\right)^{0.14}$$

$$h_o = 520.7\ W/m^{2o}C$$

After getting both the heat coefficient value, next we will calculate the overall heat transfer coefficient, U.

$$q = UA\Delta T \tag{14}$$

$$U = \frac{1}{9720W/m^{2o}C} + \frac{1}{520.7W/m^{2o}C} + \frac{0.001m}{18.5W/mC}$$

$$= 322.12\ W/m^{2o}C$$

$$The\ effective\ heat\ transfer\ area, A = \frac{q}{U\Delta T}$$

$$= \frac{4086.2kW}{\frac{322.12W}{m^{2o}C} \times 28.1}$$

$$= 451.4\ m^2$$

4.1.4 The Pressure Drop inside the HE

Pressure drop describe the decrease in pressure in the tube/plate from one point to another point downstream. This is due to the friction of the fluid against the wall of the HEX. The wall of the HEX properties such as the convergence, divergence, turns and other physical properties affect the pressure drop.

SHTE pressure drop:

$$\Delta p = \frac{\rho \times v^2 \times f \times L}{2 \times D_h} \tag{15}$$

$$v = velocity\ of\ fluid = \frac{\dot{m}}{\rho A} \tag{16}$$

$A = cross\ sectional\ area$

$L = length\ of\ tube$

$D_h = hydraulic\ diameter = diameter\ of\ tube$

$$f = friction\ factor\ inside\ tube = \frac{0.25}{\left[log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \tag{17}$$

$Given\ \varepsilon = 0.002$ [3]

$$f = \frac{0.25}{\left[log\left(\frac{0.002}{3.7(0.01483m)} + \frac{5.74}{59591^{0.9}}\right)\right]^2}$$

$$= 0.1214$$

$$= \frac{(0.27\frac{kg}{s})^2 \times 0.1214 \times 6.096\, m}{2 \times 0.01483m \times 1000\frac{kg}{m^3} \times (\frac{\pi \times 0.01483m^2}{4})^2}$$

$$= 61021\ \frac{kg}{m^2.s}$$

4.1.5 Pumping Power

For the STHE, the pumping power is:

$$P = \frac{\Delta p \dot{m}}{\rho} \quad (18)$$

$\dot{m} = overall\ mass\ flow\ rate$

$$= \frac{61021Pa \times 75kg/s}{1000kg/m^3}$$

$$= 4577\ W$$

The pumping power of COMPABLOC is:

$$= \frac{84900Pa \times \frac{75kg}{s}}{\frac{1000kg}{m^3}}$$

$$= 6368\ W$$

4.2 Cost Analysis

For the cost calculation, most of the value will be estimated to avoid any privacy breaching of the company policy. A few factors are considered in the cost calculation such as the cost of the STHE and the COMPABLOC and the maintenance cost of both HE.

4.2.1 Estimated Cost of Heat Exchanger

For the price of the heat exchanger, it can be estimated from table 4.2:

Table 4.2: Common price of heat exchanger (stainless steel) per ft^2 [12]

Shell and tube heat exchanger	$ 30-60
Plate	$ 25-40
Spiral	$ 50-70
Special tubular	$ 50-60

A shell and tube heat exchanger has a price ranging from $30-60 per square foot. For this research, from the calculation in section 4.1.3, the total heat transfer exchange area is 4857 ft^2. Based on the table 4.2, the total cost is estimated around RM 1 020 390.00

For the COMPABLOC, the total heat area is taken from appendix 2. The price is estimated around RM 300 000.00

4.2.2 Pumping Cost of the Heat Exchanger

From the result in the analytical analysis, we managed to get the pumping power of the pump for both heat exchangers. The pump efficiency is estimated around 0.87[9].The rate of the industrial electric is estimated around RM0.17/kWh [12]. The cost of pumping power for the STHE is calculated using the equation below:

$$\frac{24h}{1\,day} \times \frac{365\,days}{year} \times 5years \times pumping\ power \times \frac{RM0.17}{1kWh/0.87} \qquad (19)$$

The pumping cost of STHE in 5 years time is around RM 29 650.00

The pumping cost of COMPABLOC in 5 years time is around RM 41 252.00

4.2.3 Maintenance Cost of Shell and Tube Heat Exchanger

The maintenance cost is estimated from data given by PETRONAS PENAPISAN MELAKA. A few aspects are considered such as the work done by civil team, the manpower cost, the loaning of tools and equipment and spare part replacement. Some of the cost is calculated per day. The maintenance could take 4-7 days, depending on the condition of the SHTE. Table 4.3 shows the aspect taken into account for the maintenance of STHE.

Table 4.3: Maintenance cost of SHTE

Maintenance Aspect	Cost	Estimated Days Needed	Total cost
Loaning of Bundle Puller	RM4 500.00 per day	2	RM 9 000.00
Manpower Cost	RM4 000.00 per day	4	RM 16 000.00
Civil Cost	RM5 000.00 per day	4	RM 20 000.00
Loaning of Crane	RM4 500.00 per day	2	RM 9 000.00
Loaning of Hydrojet Equipment	RM8 000.00 per day	2	RM16 000.00
Transportation Cost	RM2 000.00-RM5 000.00	4	RM5 000.00
Gasket And Bolt Replacement	RM2 000.00-RM5 000.00	2	RM5 000.00
Control Torquing	RM15 000.00 per 3 days of shutdown	3	RM15 000.00
Overall cost			**RM95 000.00 (maximum cost)**

4.2.4 Maintenance Cost of COMPABLOC

For the COMPABLOC, according to Evae Andersson (2009) a brand new unit would not need maintenance for the first 5 years.

4.2.5 Replacement Cost Analysis

The replacement cost analysis studies the impact of capital cost, annual expenses, and the value of both HE. This calculation will determine whether the replacement can be justified.

The market value of the HE is calculated by using the equation taken from [13]:

$$BV_k = B - d_k^* \tag{20}$$

BV_k : *Book value at end of year, k*

B : *cost basis*

d_k^* : *cumulative depreciation through year k*

$$d_k^* = k.\frac{B - SV_N}{N} \tag{21}$$

SV_N : *estimated of salvage value at end of year N*

N : *depreciable life of asset*

Cost basis refers to the capital cost of the HE inclusive of the allowable adjustment. For this research, we'll consider only on the capital cost of both HE. The depreciable life of the asset is estimated around 20-25 years, taking consideration of technological change and also the material resistance to the salt water. The salvage value of the equipment would be 0 by the end of the year N. For the STHE, it has been used for 17 years so the present market value after 17 years is:

$$d_k^* = 17.(1\ 020\ 390.00 - 0)/25$$

$$= RM693\ 865.00$$

$$BV_k = RM1\ 020\ 390.00 - RM693\ 865.00$$

$$= RM326\ 525.00$$

For the next 5 years, the market value of the STHE would be:

$$d_{23}^* = 23.(1\ 020\ 390.00 - 0)/25$$

$$= RM938\ 759.00$$

$$BV_{23} = RM1\ 020\ 390.00 - RM938\ 759.00$$

$$= RM81\ 631.00$$

For COMPABLOC, in the next 5 years, the market value would be:

$d_5^* = 5.(300\ 000.00)/25$

$= RM60\ 000.00$

$BV_5 = RM300\ 000.00 - RM60\ 000.00$

$= RM240\ 000.00$

Table 4.4 Cost Considered for SHTE and COMPABLOC

	STHE	COMPABLOC
Capital Investment (cost of equipment)	$RM1\ 020\ 390.00$	RM300 000.00
Maintenance (once in 5 years) + operating cost	RM 95 000 + RM29 650.00	RM 41 252
Market value after 5 years of study(S)	RM 81 631.00	RM 240 000.00
Present market value (I)	RM 326 525.00	RM 300 000.00

The capital cost recovery is calculated based on equation from [13].

$$Capital\ recovery = I\left(\frac{A}{P}, i\%, N\right) - S\left(\frac{A}{F}, i\%, N\right) \quad (22)$$

I : *initial investment for the project*

S : *market value at end of study period*

N : *study period*

The i% is estimated around 10%, the period of study would be around 5 years and the value of A/P and A/F is taken from table C-13 in [11].

For SHTE the capital cost recovery:

$Capital\ recovery = RM326\ 525(0.2638, i\%, 5) - RM81\ 631.00(0.1638, i\%, 5)$

$= RM72\ 766.00$

For COMPABLOC, the capital recovery cost:

$$Capital\ recovery = RM300\ 000(0.2638, i\%, 5) - RM240\ 000(0.1638, i\%, 5)$$

$$= RM39\ 828.60$$

CHAPTER 5

RESULT AND DISCUSSION

5.1 Analytical Analysis Result

The calculations in the analytical analysis part in part 4.1 produce the result in table 5.1.

Table 5.1: Comparison between STHE and COMPABLOC.

	Shell and Tube Heat Exchanger	COMPABLOC
Heat transfer area, m^2	451.4	191.7
Pressure drop, Pa	61 021	84 900
Pumping power, Pa	4577	6368

5.1.1 Heat Transfer Area

Heat transfer area refers to the effective area of the heat exchanger. In table 5.1, we can see that the COMPABLOC area is much lesser than STHE. This contributes to a much smaller heat exchanger and saves a lot of space in the plant. The figure in appendix 3 shows the configuration of the COMPABLOC and the data in appendix 2 shows the specification of the COMPABLOC. To check this result, we compare it with the study done by Alfa Laval [3]. They found out that the ratio of heat transfer area of STHE and COMPABLOC is around 3-5:1. For this project, the heat transfer area ratio of SHTE to COMPABLOC is shown below:

$$\frac{STHE}{COMPABLOC} = \frac{451.4}{191.7}$$

$$= 2.4:1$$

The ratio is a bit far from the ratio estimated by Alfa Laval. This inaccuracy is maybe due to the estimation of a few properties of fluids while doing calculation for the heat transfer area of STHE.

The heat transfer area affects a lot on the price of the heat exchanger. Figure 5.1 shows the relationship of the heat transfer area and also the cost of the heat exchanger.

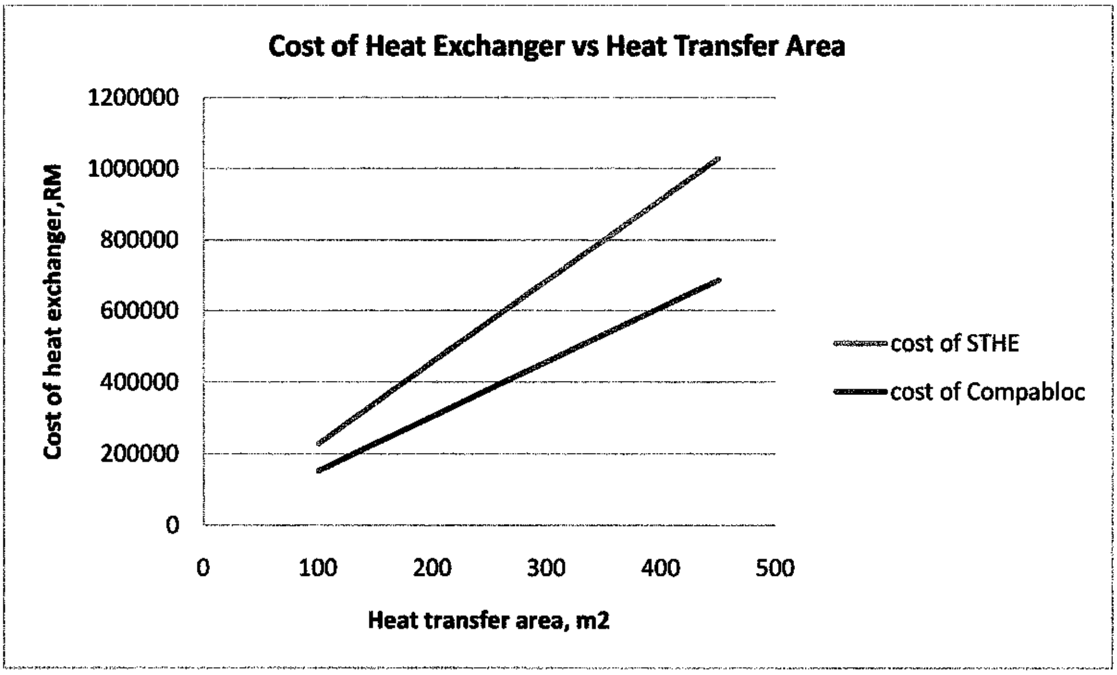


Figure 5.1: Relationship between Heat Transfer Area and the Cost of the Heat Exchanger.

The graph show that the bigger the heat transfer area, the more expensive the cost to purchase a heat exchanger. This is due to the amount of material needed to manufacture the heat exchanger.

5.1.2 Pressure Drop

Based on table 5.1, COMPABLOC have higher pressure drop between the plates which causes the shear stress on the wall higher compared to STHE. The high shear stress contributed to a better self cleaning effect in the heat exchanger, where the flow of the fluid help to remove sediments/fouling agent that could block the passage of the HE. In the previous research done by Alfa Laval [3], the ratio of the STHE pressure drop to COMPABLOC pressure drop is around 1.2:1. For this project, the calculated SHTE pressure drop ratio to COMPABLOC pressure drop:

$$\frac{STHE}{COMPABLOC} = \frac{61\,021}{84\,900}$$

$$= 0.71\colon 1$$

Even though the result is quite far from the studies done by Alfa Laval, we have to consider that we are using theoretical formula for the calculation, with a lot of assumption. But the trends still shows that COMPABLOC have higher pressure drop than STHE.

Figure 5.2 shows the relationship between the pressure drop and the shear stress inside the tube/channel.

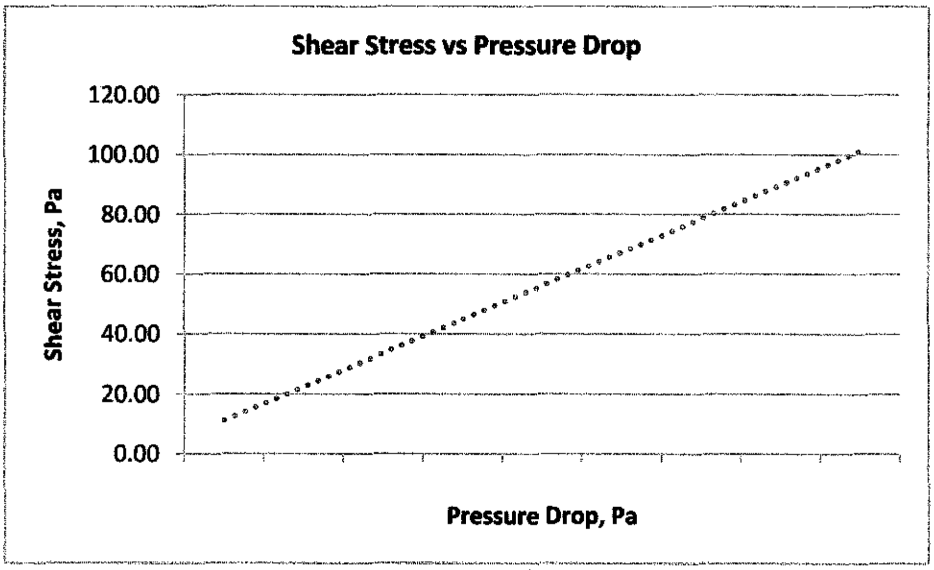


Figure 5.2: Shear Stress versus Pressure Drop Graph

From this graph, we can observe that the as the pressure drop in the tube increase, the shear stress will also increase as well. Figure 5.3 shows the relationship of the STHE tubes length and the pressure drop inside the tube.

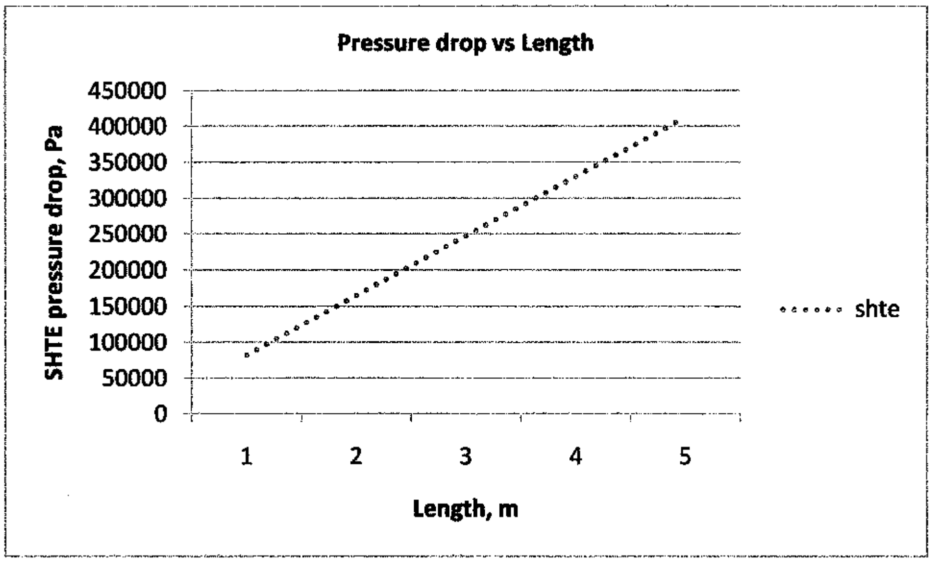


Figure 5.3: Graph of Pressure Drop of COMPABLOC and STHE versus Length of Tube/Plate

The graph shows that the increase of length in the STHE trigger an increase in the STHE pressure drop. But, longer tubes attributes to a more expensive STHE and it also consumes a lot of space in plant. For example, for a 10m tube, it has the highest pressure drop but in the plant, it needed at least 20m space for cleaning.

5.2 Cost Analysis Result

The equivalent uniform annual cost (EUAC) of both equipments is as calculated below. The equation is taken from [13]:

MARR = 10%, EUNC = 10% [13]

Table 5.2: EUNC Cost for STHE and COMPABLOC

Study period = 5 years	SHTE	COMPABLOC
Annual expenses = (maintenance cost + operating cost)	RM 124 650.00	RM 41 252.00
Capital recovery cost(CRC) = Present Market Value(A/P,10%,n years) – Market Value after n years(A/F,10%,n years)	RM 244 894.70	RM 60 000.00
EUNC = AE + CRC	RM 369 544.00	RM 101 252.00

Based on the table 5.2, the EUNC of COMPABLOC is lower than STHE, thus the SHTE must be replaced immediately.

By using the payback period method, we consider the cost that we can save by using COMPABLOC by comparing both of the maintenance cost.

$$Saving\ from\ maintenance = RM\ 95\ 000.00 - RM0$$

$$= RM\ 95\ 000.00$$

$$Payback\ period = \frac{RM\ 300\ \ 000.00}{RM\ 95\ 000.00}$$

$$= 3.2\ years$$

The payback period is only 3.2 years.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the analytical analysis that has been made, the heat exchange area of COMPABLOC is much smaller than STHE for the same thermal duty. The area of heat transfer for COMPABLOC is just 192m^2 compared to the STHE which is around 451.4 m^2. The pressure drop is also much higher, promoting more self cleaning effect that could reduce the fouling effect on the heat exchanger.

For the cost analysis part, based on the replacement analysis, the equivalent uniform cost (EUNC) of the COMPABLOC which is lower than the shell and tube heat exchanger indicates the need to change the current HEX.

The replacement study is justified, as the new heat exchanger have less area, which contributes to less space for installing the heat exchange and from the cost analysis part, the replacement should be carried out.

6.2 Recommendations

In the future, this project could be improved by doing analysis using software that can simulate the flow inside the COMPABLOC. By using software, the data from the ALFA LAVAL could be used to construct a similar plate heat exchanger and the result would be much accurate.

Besides that, since there a lack of information on the corrugated cross flow plate heat exchanger, I suggest a study on this type of exchanger should be established to get a clearer view on the impact of the corrugated plate to the flow and from this study, the mathematical model would be constructed to help in the analysis of the heat exchanger.

REFERENCES

[1] Frank Kreith. 1998, *The Mechanical Engineering Handbook*, CRC Press, pp. 118-182

[2] Alfa Laval AB, <http://www.fundinguniverse.com/company-histories/Alfa-Laval-AB-Company-History.html>, August 2009.

[3] Evae Andersson.2005, *Alfa Laval Packinox*, Alfa Laval.

[4] Alfa Laval. 2005, *Condensor and Reboiler for Space Age.*

[5] Alfa Laval. 2005, *The Compact Heat Exchanger Cuts Downtime and Service Cost: Nynas Refinery in Gottenburg Sweden.*

[6] Alfa Laval. 2005, *A Condensor and Reboiler for the Space Age: Saving Space at the Syzran Oil Refinery.*

[7] Alfa Laval. 2005, A *Perfect Fit for Tamoil.*

[8] Kakac,T. Burgles, F, Mayinger, H. Yuncu. 1999, *Heat Transfer Enhancement of Heat Exchanger*, Kluwer Academic Publishers, pp. 185-206.

[9] Incropera, DeWitt, Bergman and Lavine. 2007, *Introduction to Heat Transfer*, Wiley Asia Student Edition, pp. 631-669.

[10] Clayton T. Crowe. 2005, Donald F. Elger, John A. Robertson, *Engineering Fluid Mechanics*, Wiley International Edition, pp. 369-417.

[11] Bjorn Wilhelmson, Klas Wimmersted, Fredrik Bertilsson. 2001, *Adept Plate Technology, Heat Transfer Theory.*

[12] Alan Ferraro, March 1, 2006, <http://www.process-heating.com/CDA/Archieves/8a3a404a85ca9010VgnVCM100000f932a8c0>, August 2009.

[13] William G. Sullivan, Elin M. Wicks, James T. Luxhoj. 2006, *Engineering Economy*,Pearson International Edition, pp. 383-423.

[14] <www.aseanenergy.org/download/electricity_tariff/Malaysia-Electicity_Tariff.pdf> September 2009.

APPENDIXES

Appendix 1: Specification Sheet for Heat Exchanger E1127A-D

Table A.1: 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
Mass flow rate, kg/s	47	75
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 2: COMPABLOC Specification

Table A.2: Process data sheet of COMPABLOC CPL75

		Hot side	Cold side
Fluid	Unit	LSWR	Water
Density (average)	kg/m^3	875.0	976.9
Specific heat capacity (average)	kJ/(kg*K)	1.67	4.18
Thermal conductivity (average)	W/(m*K)	0.137	0.662
Viscosity (inlet)	cP	8.74	0.426
Viscosity (outlet)	cP	35.2	0.358
Mass flow rate	kg/s	47.00	75.00
Inlet temperature	°C	131.0	66.0
Outlet temperature	°C	79.1	79.0
Pressure drop	kPa	86.9	84.9
Heat Exchanged	kW	4075	
L.M.T.D.	K	28.2	
O.H.T.C clean conditions	W/ (m^2*K)	870.2	
O.H.T.C service	W/ (m^2*K)	753.0	
Heat transfer area	m^2	191.7	
Duty margin	%	15.6	
Shear Stress	Pa	50.97	47.28
Relative directions of fluids	Counter current		
Unit orientation	Vertical		
Number of plates	300		
Number of passes	5		
Grouping	4*30+1*30 M , 4*30+1*31 M		

Appendix 3: CPL75 Drawing

Figure A1: Front, left and top view of CPL75