Report of Cooperative Education

Plant Wide Energy Map for Optimization Hot Oil Utility and Waste Heat Recovery Unit

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ABSTRACT

This project is cooperative with Rayong gas separation plant, PTT public Company Limited, which provides energy services by transporting natural gas from the gulf of Thailand to the gas separation process. The major problem in Rayong gas separation plant is the excessive energy consumption from the production process, especially in waste heat recovery unit (WHRU). Thus, this project aims to generate the plant wide energy map to identify error in plant for saving production cost in the future. There are the prototypes of the plant wide energy map to optimize hot oil utility as well as WHRU. In the first part, Microsoft Excel program was used to examine the total energy used in Rayong gas separation plant. In this part, it can be divided into 2 steps; input energy calculation using low pressure fuel gas and energy calculation from the hot oil user system. It was found that the simulated plant wide energy map was relatively close to the current value. So, this program can also be used to monitor unit operations at the Rayong gas separation plant. In optimization part, exhaust gas discharged in the gas pipeline processing plant (GPPP) is considered as waste heat and need to be recovered to heat hot oil in the gas separation plant unit 5 before sending to users in gas separation plant unit 6. In this part, Aspen Hysys simulation program was used to generate the model of WHRU and to determine the appropriate flow rate of hot oil utility as well as amount of fuel saving for this project. After simulation, it was found that fuel saving is about 5000 Nm^3/h and cost saving is about 200 million Baht/year, which are 63.65% of internal rate of return and break-even point in 29.8 months, respectively.

Keywords: Plant Wide Energy Map, Low Pressure Fuel Gas, Hot Oil User, Hot Oil Utility, Waste Heat Recovery Unit

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Finally, I sincerely hope this co-operative project report will be of benefit to those who are interested and if anything goes wrong. I would like to receive and apologize for this opportunity.

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A = Surface area used for heat exchange (m^2)

A_s = Heat transfer surface area (m^2)

c_p = Specific Heat Capacity (kJ/kg.K)

Cr = Capacity ratio

$\frac{dT}{dn}$ = Slop of the temperature in the direction (x) of the heat transfer

E = Heat loss (MJ /h)

h = Convection heat coefficient (W/m^2K)

h(t) = Specific enthalpy of waste heat (MJ/kg)

HHV = Total heating value (MJ/m^3)

HHV_i = Heating value of gas mixture (MJ/m^3)

Hv = Specific heat of fuel (kJ/K)

k = Thermal conductivity (W/m.K)

LHV = Lower heating value (MJ/m^3)

m = Mass flow rate of the waste heat source (kg/h)

$\dot{m}$ = Mass flow rate (kg/h)

Mf = Hot oil consumption rate (kg/h)

Mo = Flow rate of hot oil (kg/h)

Q = Heat transfer rate (W) or (btu/s)

Q_b = Heat radiation that transfer through opaque object (W)

Q_n = Rate of heat transfer in the direction (W/m^2)

$\dot{Q}$ = Actual heat transfer rate (W)

$\dot{Q}_{max}$ = Maximum possible heat transfer rate (W)

T = Absolute temperature (K)

T_r = Return temperature of hot oil (°C)

T_s = Supplied temperature of hot oil (°C)

T_w = Temperature at the surface of the object (K)

T_∞ = Temperature that flow independently of the liquid (K)

ΔT = Difference temperature (K)

ΔT_m = Logarithmic mean temperature difference (K)

U = Overall heat transfer coefficient (W/m^2K)

$\dot{V}$ = Volumetric flow rate (m^3/h)

y_i = Molar ratio of gas

ρ = Density (kg/m^3)

ε = Heat transfer effectiveness

σ = Constant of Stefan-Boltzmann (5.67×10^{-8} (W/m^2K^4))

η = Efficiency (%)

CHAPTER I

INTRODUCTION

1.1 Background

Rayong gas separation plant, a subsidiary of PTT public company limited, is a major gas separation plant operator in Thailand. There are 5 natural gas separation plants to separate various hydrocarbon compounds. Gas separation units 1-3, 5 and 6 are located in Map Ta Phut Sub-District, Muang District, Rayong Province and the fourth unit in Khanom District, Nakhon Sri Thammarat Province.

In the past, Rayong gas separation plant had a nameplate capacity of 2,660 million cubic feet per day (MMSCFD). Presently, the sixth unit has a processing capacity of 800 MMSCFD. Due to continuous effort to improve efficiency of the gas separation plants, a combined processing capacity of every unit in 2012 is 2,740 MMSCFD. However, gas from the gulf of Thailand consists of various valuable hydrocarbon components, which can be extracted as starting materials of many products instead of using as fuel only. These gases can be separated before being sent to the power plants, which play a key role in industrial development in the eastern seaboard and along the pipeline route especially the petrochemical industry as well as other related industries.

Nowadays, the major problem in the production process is an increasing of energy consumption for combustion process. Decreasing energy in combustion process can significantly reduce the operating cost and carbon dioxide releasing, which is a main cause of environmental impact. However, the sector where most energy is consumed in production unit is not known. Therefore, they became the primary driving force to investigate efficient ways to identify the energy consumption of these manufacturing subsectors and to reduce energy consumption.

This project aims to generate the plant wide energy map to identify error in plant for minimizing the operation and production costs in the future. Another part of this project is to optimize the flow rate of hot oil in waste heat recovery unit and by pass hot oil from gas separation plant unit 5 to gas separation plant unit 6 for sorting out what causes excessively energy consumption in gas separation plant unit 6.

1.2 Objective

To reduce amount of fuel used in waste heat recovery unit in gas separation plant unit 6 of Rayong gas separation plant.

1.3 Scopes of work

1) Study an overview of hot oil utility and waste heat recovery unit in gas separation plant unit 6.

2) Study the production process in Rayong gas separation plant.

3) Calculate heat transfer values of the heat exchanger to create a plant wide energy map for each unit in Rayong gas separation plant.

4) Design the plant wide energy map of each unit in gas separation plant using Microsoft Excel program.

5) Simulate hot oil utility and waste heat recovery unit in gas separation plant unit 6 using Aspen Hysys program and reference value from plant wide energy map.

6) Enhance the heat exchanger efficiency of hot oil utility in gas separation plant unit 6 by optimizing waste heat recovery unit.

1.4 Expected outputs

1) Using the obtained plant wide energy map to identify the problem in the heat exchanger system.

2) Choosing the most appropriate temperature and flow rate for heat exchanger in hot oil system of gas separation plant 6 from simulation program.

CHAPTER II
LITERATURE REVIEW

2.1 Heat transfer of heat exchanger [1,12]

The process of heat transfer can be divided into 3 methods, i.e., conduction heat transfer, convection heat transfer, and thermal radiation heat transfer.

1) Conduction heat transfer

Conduction heat transfer is a type of energy transfer from one object to another object. In this case, heat exchanging will occur from the vibration of molecules that connect together. It may also occur from the movement of free electron from high temperature area to lower temperature area without any movement of an object. This type of heat transfer will only occur with solid object, however, for liquid and gas, is heat transfer will only at the same time with the convection heat transfer.

The heat transfer of an object will be based on Fourier theory [12], which is the basic equation of conduction. It explained that the heat transfer occur at specific area will correspond with the rate of temperature changes with the direction of $\frac{dT}{dn}$. Additionally, a perpendicular area with the direction of convection heat transfer A will follow the direction n as display in Figure 2.1. It can be written into an equation as follows.

$$Q_n = -kA\frac{dT}{dn} \qquad (2.1)$$

Where Q_n is rate of heat transfer in the direction of unit W/m^2.
k is a Thermal conductivity in the unit of W/mK.
A is a perpendicular area of direction n in a square meter unit (m^2).
$\frac{dT}{dn}$ is the slope of the temperature (T) in the direction (x) of heat transfer.

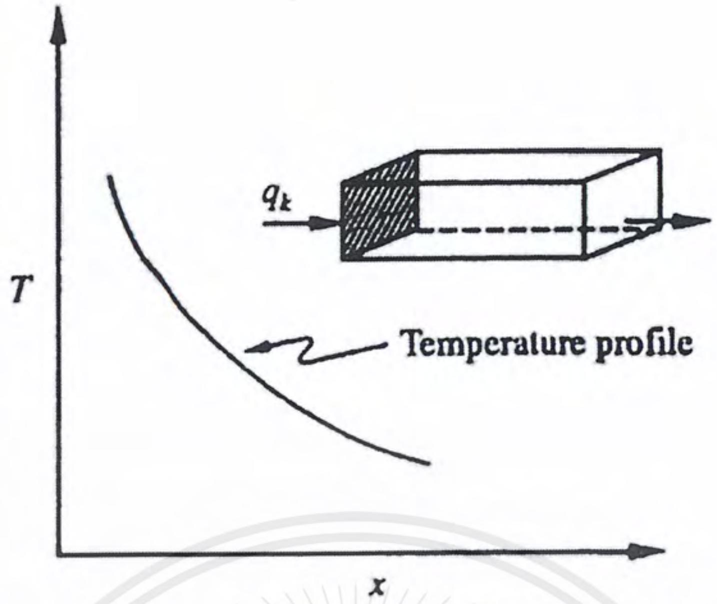


Figure 2.1 Sketch illustrating the direction of heat flow and coordinate system [12]

2) Convection heat transfer

It is a process of heat transfer by the movement of liquid or heat transfer beween the surface of object with the liquid. The heat transfer occured between the surface of the object is be more important than the heat transfer within the liquid itself, especially the heating equipment in industrial sector.

The convection can be divided into the flow of liquid that occur naturally. This is due to the differences of the temperature or density which is called free or natural convection. Convection that derived from pump or fan is called "forced convection". This can be calculated from the convection equation which is called Newton's Cooling Law as follows.

$$Q = hA(\Delta T) \qquad (2.2)$$

Where h is heat coefficient in the unit of W/m^{2}K.

A is a perpendicular area of direction n in the unit of m^2.

ΔT is a difference of temperature in the unit of K.

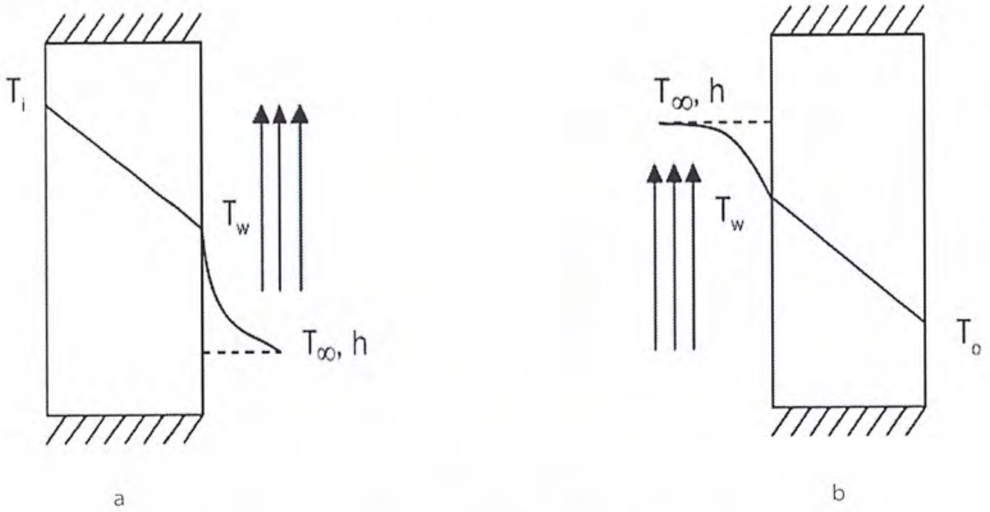


Figure 2.2 Convection heat transfer a) $T_w > T_\infty$ b) $T_\infty < T_w$ [1]

Where T_∞ is the temperature that flow independently of the liquid in the unit Kelvin (K).

T_w is the temperature at the surface of the object in the unit Kelvin (K).

3) Thermal radiation heat transfer

This is another type of heat transfer that does not need medium in the process of heat conduction or heat convection. It can occur on the surface of solid, liquid, and gas. Thermal radiation of heat transfer will shift greatly in vacuum condition and can also move in the form of electromagnetic wave.

However, if an object absorbs the electromagnetic wave, it will receive energy and then the temperature of an object is increased. The object that consists of thermal radiation properties and can absorb radiation is called black body. Based on Stefan-Boltzmann's theory as follows.

$$Q_b = \sigma A T^4 \qquad (2.3)$$

Where σ is constant of Stefan-Boltzmann is equivalent to 5.67×10^{-8} W/m^2K^4.

Q_b is heat radiation that transfer through opaque object in unit W.

T is an absolute temperature of an object in the unit Kelvin (K).

2.2 Heat exchanger [4]

Heat Exchanger is a tool used to transfer heat from one fluid to another when the temperature is different. The heat is transferred from the higher temperature fluid to the lower temperature fluid. Heat transfer occurs through the duct wall of both types of fluid and does not mix. It is widely used in industries such as the oil industry, petrochemical industry, etc. Heat exchangers are used to for increase the temperature of crude oil, to reduce the temperature of oil or gas and used to recycleheat energy from recycled fluids. Examples of heat exchangers used today are condenser, heater, or evaporator, etc. The main function of the heat exchanger will depend on the direction of fluid flow and heat exchangers, which will be discussed later.

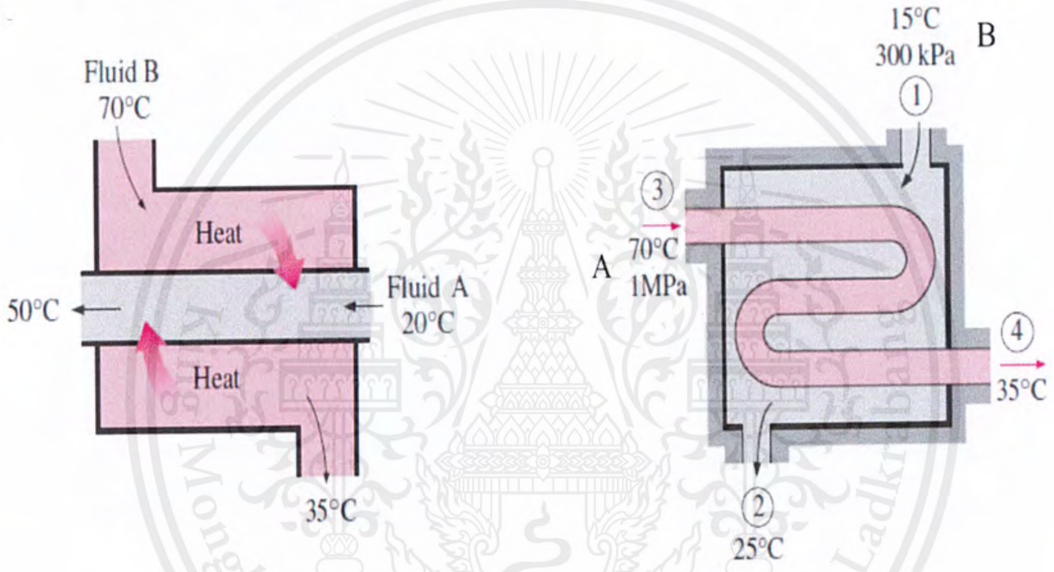


Figure 2.3 Example for Heat Exchanger [5]

2.2.1 Classification of heat exchanger [4]

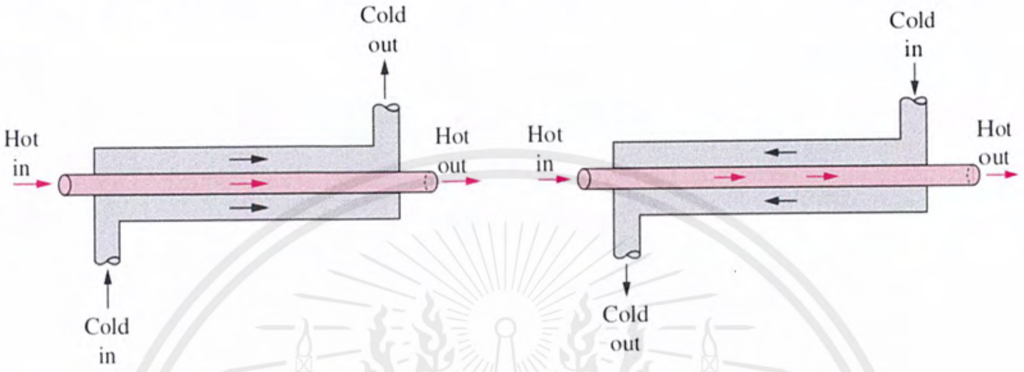
Based on characteristics of the fluid, classification of heat exchanger can be divided into 3 types:

- Parallel flow
- Counter flow
- Cross flow

And based on heat exchanger characteristics, they can be categorized into 3 types:

1) Double pipe or concentric tube heat exchanger

The tube is worn together with the fluid. It can be used to exchange heat between 2 fluids. The flow characteristics of the fluid in the heat exchanger can be parallel flow and counter flow.

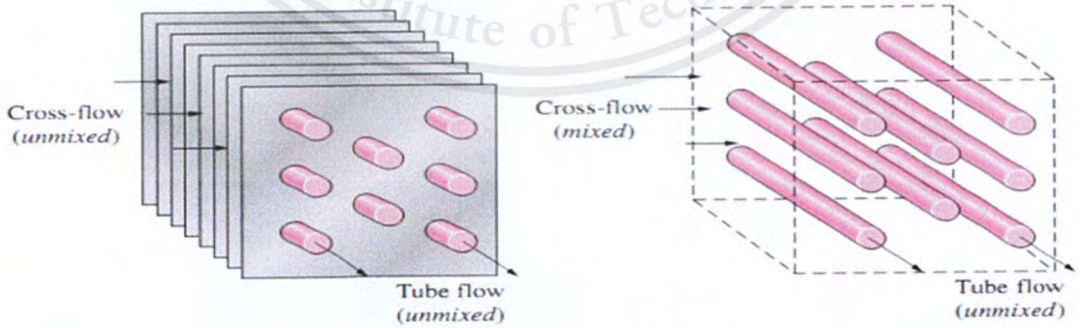


(*a*) Parallel flow (*b*) Counter flow

Figure 2.4 The double-pipe heat exchanger [4]

2) Compact heat exchanger

Fluid flow characteristic is a cross flow and often involves the exchange of heat between air and liquid such as a radiator in a car. This heat exchanger may be in the form of a single pass, double pass, and more. The cross-flow is further classified as unmixed and mixed flow.



(*a*) Both fluids unmixed (*b*) One fluid mixed, one fluid unmixed

Figure 2.5 Different flow configurations in compact heat exchangers [5]

3) Shell and heat exchanger

For fluid flow characteristics of this heat exchanger, one type of fluid is in the tube and the other fluid is in the shell. And this type of heat exchanger consists of baffles which are an integral part. A baffle offers great heat transfer capability by generated turbulent flow and. The flow characteristics of the heat exchanger are either flowing or parallel, or both. In addition, it may be designed to flow in perpendicular direction to the pipe.

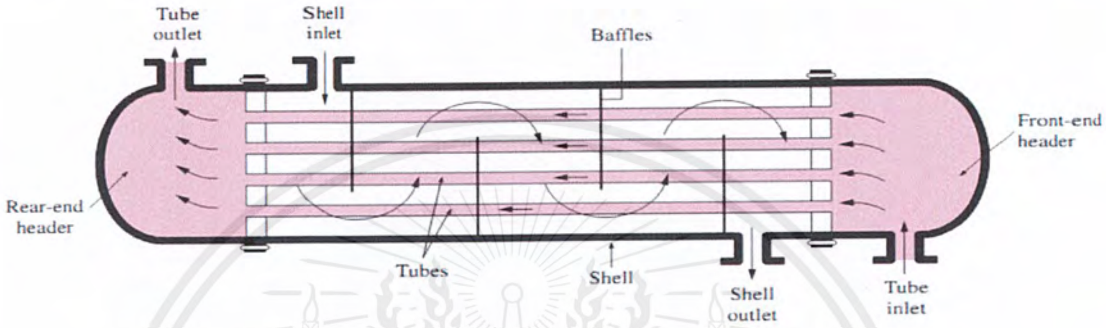


Figure 2.6 Shell and tube heat exchanger 1 shell pass and 1 tube pass [4]

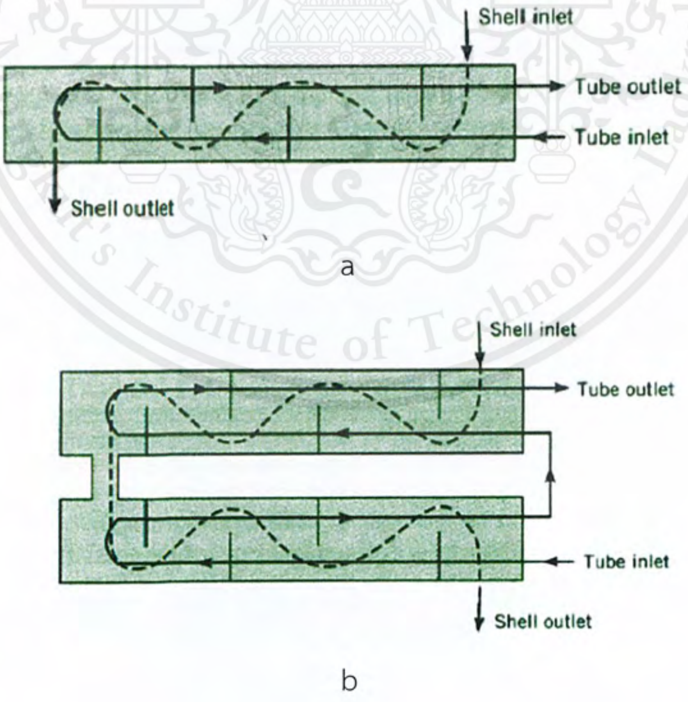


Figure 2.7 Shell and tube heat exchanger a) Liquid flow through shell once. Another type of liquid flow through tube twice b) Liquid flow through shell twice. Another type of liquid flow through tube four times. [1]

2.2.2 The log mean temperature difference (LMTD) method [1,4]

For the normal fluid temperature in the heat exchanger, there is no fixed value but it will vary from point to point. When heat is transferred from the higher temperature fluid to the lower temperature fluid even if the heat resistance of the fluid is constant, the heat transfer rate varies with the flow in the heat exchanger, because the heat transfer rate varies with the difference between the hot stream and the cool stream at the cross section.

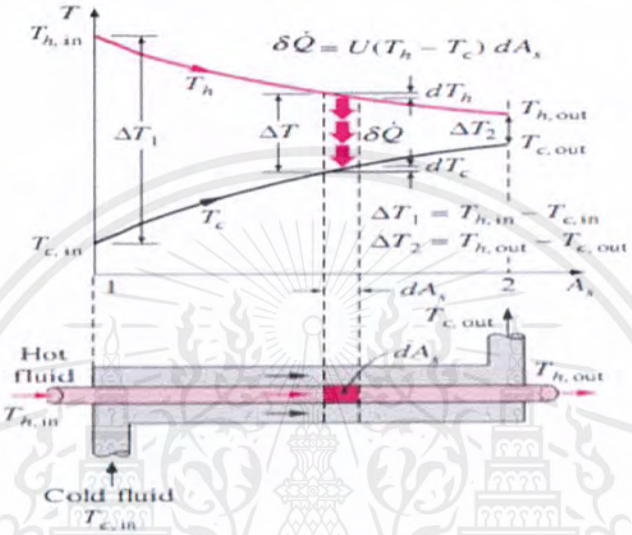
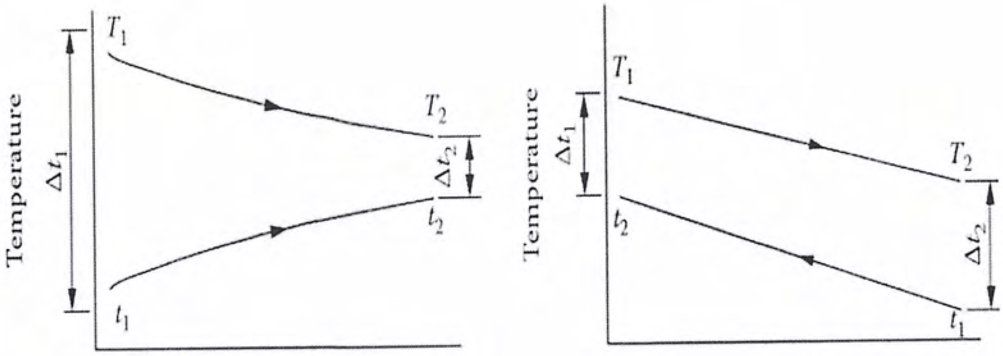


Figure 2.8 Variation of the fluid temperatures in a parallel-flow double-pipe *heat* exchanger [4]

The temperature of the hot and cool stream will be exponentially decreased and increased, respectively. However the temperature of the cool stream can not be higher than the temperature of the hot stream, even in the heat exchanger. From Figure 2.8, it can be seen that the distance between the fluid temperature curve is ΔT, so the calculation of mean temperature difference would be done by finding the log mean temperature difference and the calculation result would be called the log mean temperature difference (LMTD). The LMTD value will be useful for calculating the mean LMTD or ΔT_m from the equation as below.

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln(\Delta T_1/\Delta T_2)} \tag{2.4}$$

Where the values of ΔT_1 and ΔT_2 are the difference in inlet and outlet temperatures, respectively, depending on the type of flow as shown in Figure 2.9.



a b

Figure 2.9 Heat exchanger temperature profiles a) temperature distribution in parallel flow heat exchanger b) temperature distribution in counter flow heat exchanger [13]

1) The parallel-flow heat exchanger

The distribution of temperature and heat in the parallel-flow heat exchanger shown in Figure 2.10. It was found that the temperature difference (ΔT) would reduce with increasing distance x. The important thing for this type of heat exchanger is the temperature of fluid being always less than the temperature of hot fluid at the solution exits.

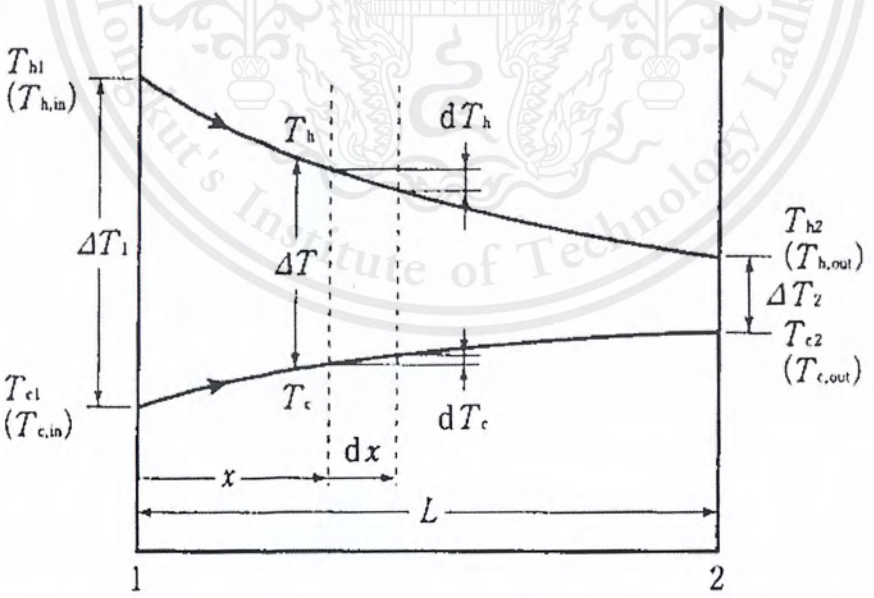


Figure 2.10 The parallel flow heat exchanger [14]

2) The counter flow heat exchanger

Counter flow heat exchanger is different from parallel flow heat exchanger. From Figure 2.11, it was found that the temperature of the hot and the cold stream which are at the same side due to the $\Delta T = T_h - T_c$ at any x distance, it is not as high as the inlet flow. The important observation is that the outlet temperature of the cold stream may be higher than the outlet temperature of the hot stream

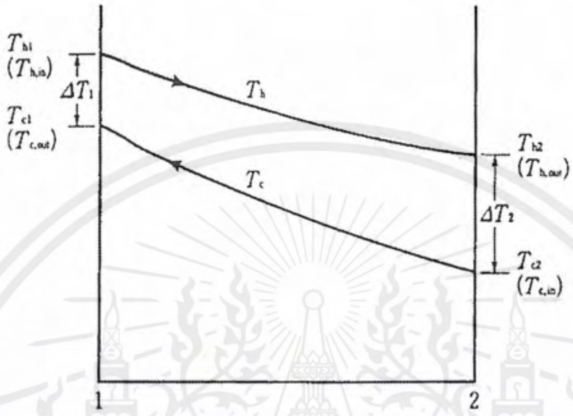


Figure 2.11 The counter flow heat exchanger [14]

2.2.3 The effectiveness-NTU method [1,4]

Because it is always necessary to know the inlet and outlet temperature for the LMTD calculation. Therefore, the effectiveness-NTU method (Kay and London, 1995) is used in temperature calculation which is only done on the LMTD. Then, LMTD is complicated when the temperature is known. The NTU calculation would have the advantage when comparing different types of heat exchangers. It is often used as a reason to choose the most appropriate heat exchanger for the given purpose. The definition of the efficiency of the heat exchanger is as follows:

$$(\varepsilon) = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{\text{Actual heat transfer rate}}{\text{Maximum possible heat transfer rate}} \qquad (2.5)$$

Actual heat transfer rate

$$\dot{Q} = C_c\,(T_{c,out} - T_{c,in}) = C_h\,(T_{h,in} - T_{h,out}) \qquad (2.6)$$

The maximum heat transfer rate is possible when:

$$\Delta T_{max} = T_{h,in} - T_{c,in} \qquad (2.7)$$

And C_{min} will create ΔT_{max}.

So it is possible to calculate the maximum heat transfer rate from:

$$\dot{Q}_{max} = C_{min}\Delta T_{max} = C_{min}\,(T_{h,in} - T_{c,in}) \qquad (2.8)$$

And C_{min} is the minimum value between C_h and C_c.

Heat transfer effectiveness (ε) can be obtained from the relationship of two-terms: NTU and Capacity ratio (Cr).

$$\text{NTU} = \frac{U \times A_S}{c_{min}} = \frac{U \times A_S}{(\dot{m} \times c_p)_{min}} \qquad (2.9)$$

And capacity ratio (Cr)

$$\text{Cr} = \frac{C_{min}}{C_{max}} \qquad (2.10)$$

It can be shown that the effectiveness of a heat exchanger is a function of the number of transfer units NTU and the capacity ratio Cr. That is,

$$\varepsilon = \text{function}\,(UA_s/C_{min},\ C_{min}/C_{max}) = \text{function}\,(\text{NTU, Cr}) \qquad (2.11)$$

Therefore, the heat capacity ratio (Cr) can be summarized in Table 2.1 as follows:

Table 2.1 Effectiveness relations for heat exchangers: NTU = Au_s/c_{min} and Cr = $c_{min}/\ c_{max}$ [3]

Heat exchanger type	Effectiveness relation
Concentric tube parallel flow	$\varepsilon = \dfrac{1-\exp\left[-NTU(1+Cr)\right]}{1+Cr}$
Counter flow	$\varepsilon = \dfrac{1-\exp\left[-NTU(1-Cr)\right]}{1-Cr\exp\left[-NTU(1-Cr)\right]}$
Shell and tube One shell pass (2, 4,...... tube passes)	$\varepsilon = 2\left\{1+Cr+\left(1+Cr^2\right)^{1/2} \times \dfrac{1+\exp\left[-NTU\left(1+Cr^2\right)^{1/2}\right]}{1-\exp\left[-NTU\left(1+Cr^2\right)^{1/2}\right]}\right\}^{-1}$
n Shell passes (2n, 4n, ... tube passes)	$\varepsilon = \left[\left(\dfrac{1-\varepsilon_1 Cr}{1-\varepsilon_1}\right)-1\right]^2\left[\left(\dfrac{1-\varepsilon_1 Cr}{1-\varepsilon_1}\right)^2-Cr\right]^{-1}$
Cross flow (single pass) Both fluids unmixed	$\varepsilon = 1-\exp\left[\left(\dfrac{1}{Cr}\right)\left(NTU^{0.22}\right)\left\{\exp\left[-Cr(NTU)^{0.78}\right]-1\right\}\right]$
C_{min} (mixed), C_{min} (unmixed)	$\varepsilon = \left(\dfrac{1}{Cr}\right)\left(1-\exp\left\{-Cr\left[1-\exp(NTU)\right]\right\}\right)$
C_{max} (mixed), C_{max} (unmixed)	$\varepsilon = 1-\exp\left(-Cr^{-1}\left\{1-\exp\left[-Cr(NTU)\right]\right\}\right)$
All exchanger (Cr = 0)	$\varepsilon = 1-\exp(-NTU)$

2.3 Waste heat recovery [7]

Waste heat is the energy flowing with the currents of air, gas, and liquid waste outside of the building or factory environment. There are two types of heat emission:

1) Hot fluid such as
   - Hot water
   - Hot oil or other hot fluid, etc.

2) Hot gases such as
   - Hot air from production process
   - Hot air from stove or oven, etc.

Waste heat is divided into temperature ranges for suitable application. The standard in separating the range of waste heat is quite close. Therefore the SI unit of temperature that will be used is as follows:

The low temperature waste heat will have a temperature range below 250 °C. It would be inappropriate to be used to produce vapor because the vapor pressure would be too low. Most of the waste heat is appropriate for direct heating such as heating fluid in the production process as shown in Table 2.2 as follows:

Table 2.2 Heat source and temperature of the low temperature waste heat [2]

Heat source	Temperature (°C)
Process steam condensate	50-90
Cooling water from:	
• Injection molding machine	35-90
• Annealing furnace	65-220
• Air compressor	30-50
• Internal combustion engine	65-120

Table 2.3 Heat source and temperature of the low temperature waste heat [2] (Continuous)

Heat source	Temperature (°C)
● Air conditioning and refrigeration condenser	35-45
● Drying, baking and curing oven	90-220
● Hot-processed liquid	35-220

The medium-temperature waste heat would be in the range of 200-600 ℃. The waste heat group is likely to be recycled for steam turbines for power production.[1] Additionally, the heating temperature is suitable for use as a heat source in the production process as shown in Table 2.3 as follows:

Table 2.4 Heat source and temperature of the medium temperature waste heat [2]

Heat source	Temperature (°C)
Steam boiler exhaust	220-380
Gas turbine exhaust	380-540
Reciprocating engine exhaust	320-600
Heat treating furnace	420-650
Drying and baking oven	220-600
Annealing furnace cooling system	420-650

High temperature waste heat would be in the range of 600-1,600 ℃, which is high quality and valuable. It is possible to produce high pressure steam by waste heat recovery. And it is also an alternative way to produce electricity for the production process as shown in Table 2.4 as follows:

Table 2.4 Heat source and temperature of the high temperature waste heat [2]

Heat source	Temperature (°C)
Aluminum refining fuenace	650-750
Zinc refining furnace	750-1,100
Copper refining furnace	750-800
Steel heating furmace	900-1,050
Cooper reverberatory furnce	900-1,100
Cement kiln (dry process)	600-750
Glass melting furnace	1,000-1,550
Solid waste incinerator	650-1,000
Fume incinerator	650-1,450

At the same time, the used of waste heat requires a heat sink such as a process that requires heating at the factory. Heat source can be divided into three sources: low temperature waste heat source that requires the temperature below 150 °C, a medium heat source that requires temperatures in the range of 150 to 250 °C, and a high temperature waste heat source that requires temperatures exceeding 500°C.

2.3.1 Recycling waste [7]

The possibility of recycle waste heat is considered by the specific factors, which are related to heat source and heat sink. The important factors that impact the possibility of recycling waste heat are as follows:

- Heat temperature/quality
- Heat quantity
- Composition

- Minimum allowable temperature
- Operating schedule, availability, and logistic.

The considerations on factor for recycling waste heat are as follows:

1) Heat temperature or quality

The temperature of the waste heat is an important factor in the possibility of recycling waste heat and have multiple levels of temperature. Additionally, an important factor is considered by the difference between the temperature of the heat source and heat sink as known as the quality of waste heat. And this will affect the details as follows:

- Heat transfer rate per heat exchanger area unit
- A range of different temperatures would affect the choice of materials and equipment to bring recycled heat.
- Theoretical efficiency of transfer or transformation of heat energy from heat source to heat sink

2) Heat quantity

It measures the amount of waste heat that can be recycled. The temperature and the mass flow ratio of the heat source will affect the amount of heat dissipation as equation:

$$E = m \cdot h(t) \qquad (2.12)$$

Where E is the heat loss in MJ / h
m is the mass flow rate of the waste heat source in kg /h
h(t) is the specific enthalpy of waste heat in MJ/ kg unit. The value would depend on the temperature.

3) Composition

Components and status of waste heat sources will affect the thermal conductivity, which will influence the performance of the heat exchanger and affect the design of the heat exchanger, restrictions on material selection, and cost.

The heat transfer rate in a heat exchanger would depend on the composition and status of the waste heat source. High density fluid would have high heat transfer coefficient. This will result in higher heat transfer rates per area unit at referred temperature.

4) Minimum allowable temperature

Acceptable minimum temperature for waste heat source would be related to the problem with corrosion of the materials used to make the heat exchanger. Heat exchangers designed from non-standard materials would be easy to damage from the temperature changes. Additionally, the combustion is based on the fuel used and is related with the components present in the exhaust gas. It affects the concentration of carbon dioxide, vapor, nitrogen oxides (NO_2), non-oxidized organic substances, and minerals.

5) Heat exchanger area requirements

Waste heat temperature is a factor that affects the heat transfer between the heat source and the heat sink, which affects the potential to bring technology to be used.

$$Q = UA\Delta T \qquad (2.13)$$

Where Q is the heat transfer rate in Watt (W) or btu /s
U is the heat transfer coefficient in W/m^2K.
A is the surface area used for heat exchange in m^2
ΔT is the difference in temperature between the heat source and the heat sink.

In addition, from the equation 2.13, the amount of heat transferred depends on the heat transfer coefficient of the material (U), the surface area used for the heat exchanger (A), and the difference in temperature between the heat source and heat sink (ΔT).

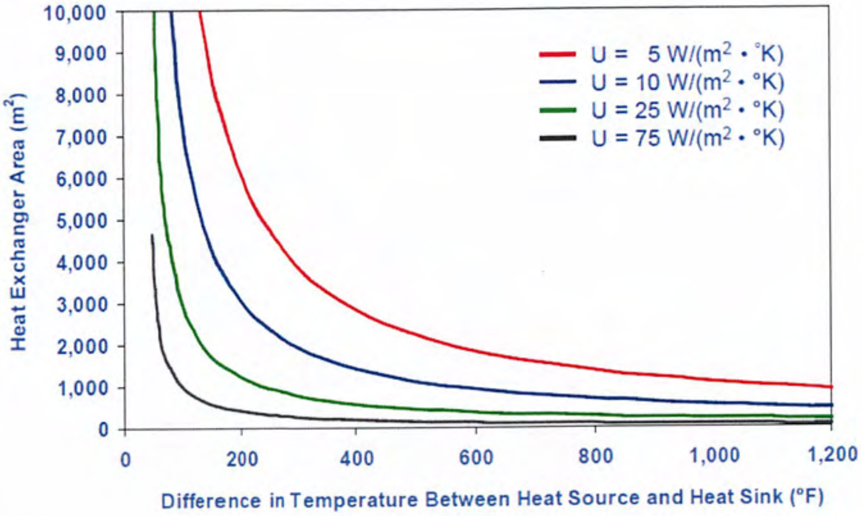


Figure 2.12 Influence of temperature difference on required heat exchanger area [7]

Figure 2.12 shown that there was a slight difference between each temperature. therefore, langer surface is needed for an heat exchanger area.

2.3.2 Thermal energy sources in petrochemical industry

Usually, the production processes in petrochemical industry are complicated. Therefore, the system improvement is difficult to perform. The main equipment of the production process is heater and distillation columns. The main thermal energy source is the steam.

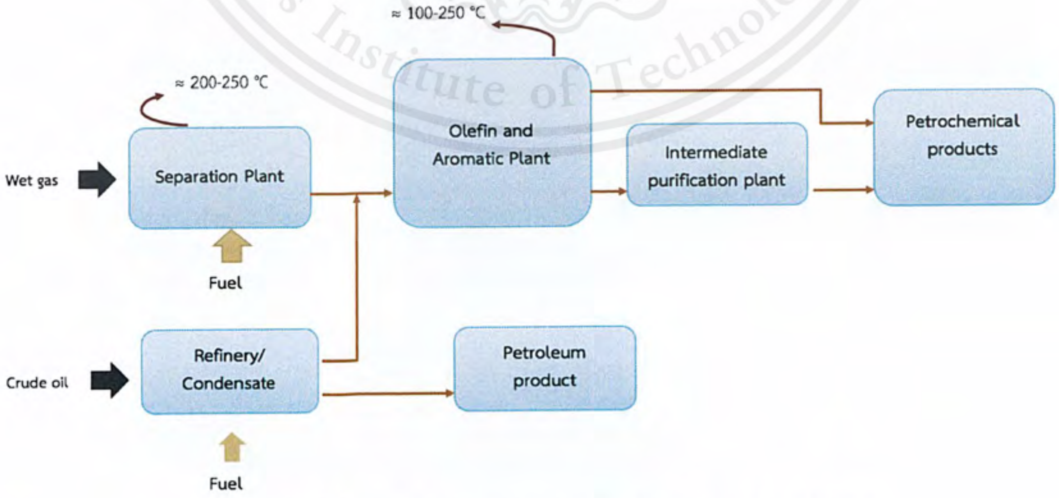


Figure 2.13 Energy consumption in petrochemical industry

Mostly, the temperature of waste heat is about 100-200°C. And there are 3 waste heat discharge points as the following;

1) Cooling Tower
2) Fin Fan
3) Product

The potential of bringing waste heat back to use in petrochemical and distillation industry can be shown in table 2.5.

Table 2.5 The potential of bringing waste heat back to use in Petrochemical and Distillation industry [7]

Thermal energy sources	Temperature Level	Heat receiving sources	Technology
1. Oven	Low	- Warm the material - Electricity generation	Heat exchanger ORC
2. Waste water condensate	Low		
3. Waste hot water	Low		
4. Waste Air	Low		
5. Exhaust gas from boiler	Low		
6. Sewerage water from boiler	Low		

2.4 Hot oil boiler system [9]

The equipment which uses liquid to transfer the heat or hot oil boiler is a thermal conduction equipment which use Thermal oil at the high temperature to transfer the heat from Hot oil boiler. The oil will flow through Heating coil in the equipment. Moreover, the material has to be good on heat transfer and resistance when the temperature is higher than 350 °C. The characteristics of boilers which use liquid to transfer the heat in the industry can be classified according to external structure and appropriation of use which will be mentioned in the following topic.

2.4.1 Types of hot oil boiler

Can be classified by the structure into 2 types as the following:

- Vertical type

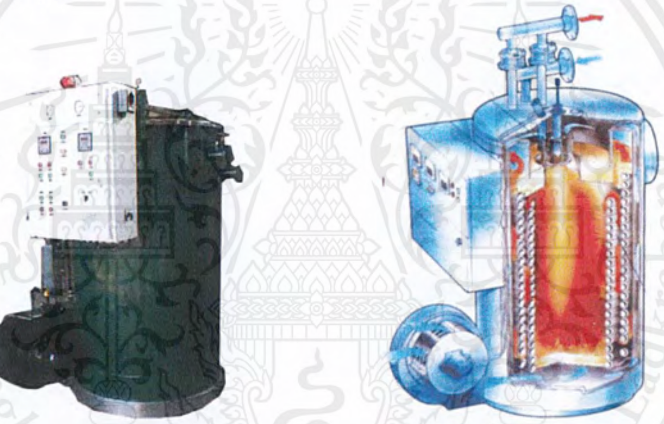


Figure 2.14 Hot oil boiler in vertical type [9]

- Horizontal type

Figure 2.15 Hot oil boiler in Horizontal type [9]

2.4.2 Type of circulatory system

The circulatory system which used to transfer the heat can be classified into 2 systems as the following:

1) Open circuit system

It is the circulatory system which the oil in the system contact directly with the air in the boiler. It makes the lifetime of thermal oil shorter because of the combination of oxygen and oil. Open circuit system is suitable for the condition which the temperature of oil is lower than 200 °C.

2) Close circuit system

It is the circulatory system which the oil has no chance to contact with the air because it is covered by an inert gas such as nitrogen which is widely used in industrial process. Therefore, there is no oxygen combined with the oil and the pressure of the system is slightly higher than the atmospheric pressure. The lifetime of the oil will be longer than open circuit system. Moreover, this system can be used at the condition that the temperature of the oil is up to 300 °C.

2.4.3 Working principle of hot oil boiler [10]

Hot oil boiler uses the burner to mix the fuel and the air by the suitable proportion for the complete combustion. The heat from this combustion will be transferred to the liquid in the heating coil in the boiler that locates around the combustion chamber. The temperature of oil in the heating coil will be higher. Then, oil will be moved outside by the work of circulating pump.

The hot oil, which is moved outside, will be transferred to heat exchanger to transfer the heat to products and the temperature of oil will drop. Then, oil will be transferred to deaerator to eliminate air bubbles before being transferred to expansion tank to support the expansion of oil at the high temperature. Then, it will be transferred to strainer to eliminate dirt. Last, oil will be back to circulating pump again to get the heat from the system. The system will work this sequence repeatedly. The work of boilers is shown in Figure 2.16.

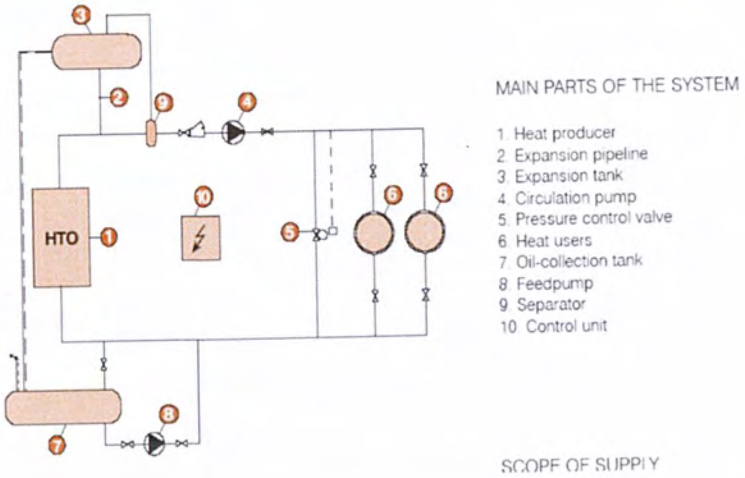


Figure 2.16 Work cycle of Hot oil boiler [10]

For Rayong gas separation plant, hot oil system uses the oil with flash point higher than 200 °C[11] to generate the heat. The fuel, which is used to heat oil, is derived from waste heat or exhaust gas of gas turbine. Moreover, the most important disadvantage of heavy hydrocarbon oil, which is used as a heating fluid, is easily subjected to thermal cracking. Therefore, this system needs to release light hydrocarbon from the system. The chart of hot oil system of Rayong gas separation plant can be shown in Figure 2.17.

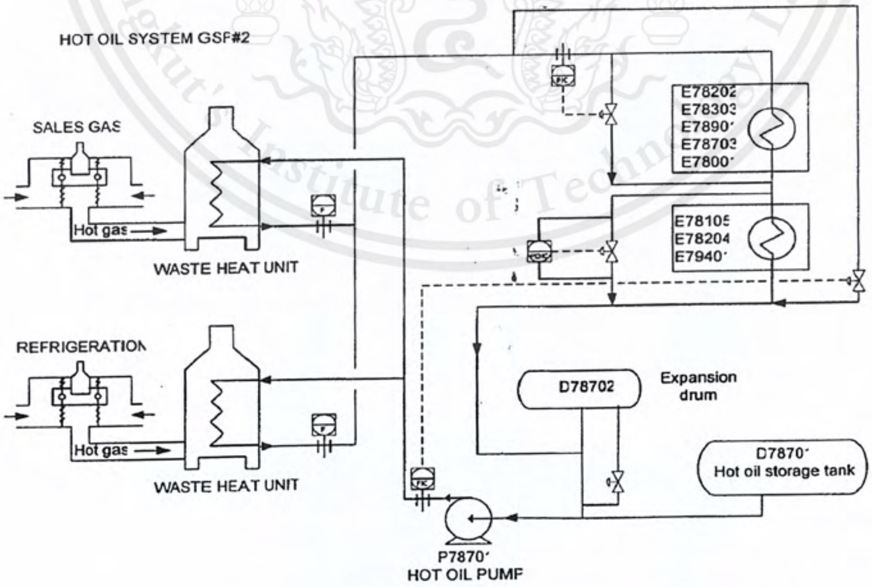


Figure 2.17 Hot oil system of Rayong gas separation plant 2 [11]

2.4.4 The efficiency of hot oil boiler

$$\text{The efficiency of hot oil boiler } (\eta) = \frac{\textbf{Heat exported by the thermal oil}}{\textbf{Heat provided by the fuel}}$$

$$= \frac{\mathrm{Mo} \times \mathrm{C_p} \times (\mathrm{T_S} - \mathrm{T_r})}{\mathrm{Mf} \times \mathrm{Hv}} \tag{2.14}$$

Where η is the efficiency (%)
Mo is flow rate of hot oil (kg/hr)
Mf is oil consumption rate (kg/hr)
$\mathrm{T_s}$ is supplied temperature of hot oil (°C)
$\mathrm{T_r}$ is return temperature of hot oil (°C)
Hv is specific heat of fuel (kJ/k)

2.4.5 Hot oil boiler technology application

Thermal oil system is widely used in industries such as:

- Chemical industry such as distillation columns, steam generator, etc.
- Food industry such as chemical reaction separated oven, deep-fat fryers and hot air oven
- Wood industry such as medium density fiber production process and wood drying
- Textile industry such as stenter frames and dryers

2.4.6 Potential of energy savings

Table 2.6 shows the case studies of cost comparison for each production process's heat supply which consists of hot oil boiler, steam boiler, and electrical system.

Table 2.6 The case studies of cost comparison for each production process's heat supply [10]

	Hot oil boiler	Electrical system	Steam boiler
1. Required heat in the production process	1,000,000 kCal/hr	1,163 kWh	1,851 kg/hr
2. Recieived heat from equipment	1,000,000 kCal/hr	1,163 kWh	1,851 kg/hr
3. Energy source	Fuel Oils	Electricity	Fuel Oils
4. Thermal efficiency	87 %	100 %	71 %
5. Heating value	9,650 kCal/hr	860 kCal/kW	9,650 kCal/kg
6. Fuel/ electricity	119 kg/hr	1,163 kWh	155 kg/hr
7. Fuel/ electricity cost	20 Baht/kg	3 Baht /unit	20 Baht/kg
8. Fuel cost at 7,200 hr./year	17,136,000	25,120,800	22,320,000

From Table 2.6, the efficiency and the cost of the electrical system is higher than others also the cost. However, when compared with hot oil boiler and steam boiler, hot oil boiler has the greater efficiency than steam boiler because the energy loss of hot oil boiler is lower.

2.5 Heating value and combustion [8]

Heating value is the thermal energy from the complete combustion under 1 atm pressure and 25°C. This heating value is equal to thermal energy from standard heat of combustion but is positive as shown in Table 2.7.

Table 2.7 Thermal conductivity of some important gases [6]

Types of gas	Thermal conductivity (W/m.K)
Hydrogen (H_2)	0.142
Helium (He)	0.129
Nitrogen (N_2)	0.024
Carobonmonoxide (CO)	0.014

Heating value can be presented in 2 ways, gross heating value or total heating value (HHV) which is the latest status of water in the system after the combustion as liquid, and net heating value or lower heating value (LHV) which is the latest status of water in the system after the combustion as vapor. The relationship of gross heating value and net heating value can be shown in Equation 2.15 as the following;

$$\text{Gross H.V} = \text{Net H.V} + \text{wt. } H_2O\ (\Delta H_{vap\ H2O}) \qquad (2.15)$$

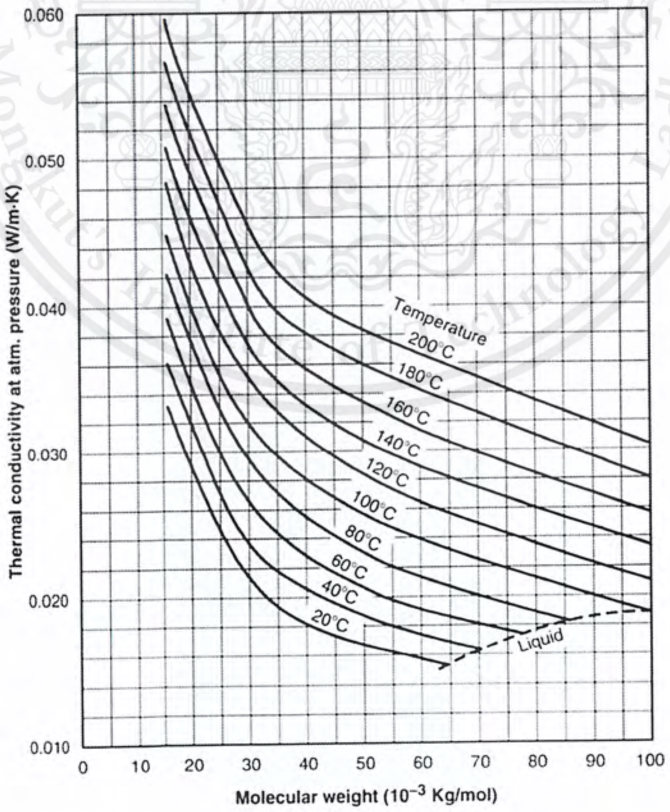


Figure 2.18 Variation in thermal conductivity with molecular weight [6]

British system and metric system often identify the heating value for fuel gas as btu/ft^3 gas at 60 °F, pressure = 30 inHg, and saturated vapor condition. When considering only the pressure of dry gas, 1 lbmol at 60 °F, pressure = 30 inHg equal to 385.2 ft^3 which called standard cubic foot (scf) for fuel gas.

In the present, SI unit sets the following conditions, 15 °C, under pressure 101325 Pa or 101.325 kPa, and dry gas as the standard condition and the unit of heating value is MJ/m^3. Therefore,

$$1 \text{ kmol, } 15\,^{\circ}\text{C, } 101.325 \text{ kPa (dry gas)} = 23.6455 \text{ m}^3$$

$$\text{and } 1 \text{ btu/scf} = 0.03796 \text{ MJ/m}^3$$

In case of natural gas, which is mixed and the component is different, heating value can be calculated by weight calculation of each gas by mass of each gas as shown in Table 2.8, the calculation of natural gas's heating value.

Table 2.8 The calculation of natural gas's heating value [8]

Component	mole frac	heating value		total heating value	
		btu/ft^3	MJ/m^3	btu/ft^3	MJ/m^3
Nitrogen	0.023	0.0	0.0	0.0	0.0
Methane	0.887	1009.7	37.694	895.60	33.435
Ethane	0.056	1768.8	66.032	99.05	3.698
Propane	0.021	2517.4	93.972	52.87	1.973
iso-Butane	0.003	3252.7	121.426	9.76	0.364
n-Butane	0.006	3262.1	121.779	19.57	0.731
Pentane mix [1]	0.004	4380.4	163.521	17.52	0.654
	1.000			1094.37	40.855

---

[1] is 0.001 n-C_5, 0.001 I-C_5, 0.002 N-C_5

<u>**Example**</u> The combustion of 1-lbmol methane can be demonstrated in the chemical equation as the following;

$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(l) + 383.171 \text{ btu} \qquad (a)$$

Latent heat of vaporization of water at 60 °F and 1–atm pressure is 1,030 btu/lb. For 2–lb water, it will be;

$$18 \times 2 \times 1{,}030 = 38{,}160 \text{ btu}$$

Net equation of water at the vapor condition

$$2H_2O\,(l) \rightarrow 2H_2O\,(g) + (-38{,}160 \text{ btu}) \qquad (b)$$

Combine (a) and (b), it will be:

$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(g) + 345{,}011 \text{ btu} \qquad (c)$$

1 lbmol of ideal gas will have the volume equal to 379 ft^3 is the net heating value of methane combustion equal to 910 btu/ft^3 and gross heating value will equal to:

$$383{,}171/379.49 = 1{,}009.7 \text{ btu/ft}^3$$

At 60°F and 1 atm pressure and Z of methane is 0.998. Therefore, gross heating value of methane in exact condition is;

$$1{,}009.7/0.998 = 1{,}001.7 \text{ btu/ft}^3$$

CHAPTER III

RESEARCH METHODOLOGY

This work aims to develop a thermal energy system in gas seperation plant by creating the plant wide energy map. After that, the information value obtained from plant wide energy map was used to simulate the waste heat recovery unit. The final part is the optimization of fuel comsumption. The outline of research methodology can be illustrated as follow.

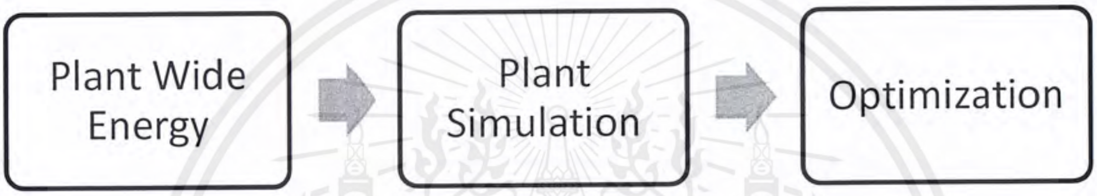


Figure 3.1 A simplified diagram to develop a thermal energy system in waste heat recovery unit of Rayong gas separation.

3.1 Simulation of the entire energy diagram of industrail factory (Plant wide energy)

Plant wide energy map is a primarily important way to identify an error in plant. It can evaluate the entire structure of thermal energy in hot oil system, waste heat recovery unit (WHRU) and heat exchanger in PTT's gas separation plant in Rayong province. In addition, it can compare the energy consumption of each equipment at the desired period. In this work, this diagram was created by Microsoft Excel and information management system "Exaquantum".

3.1.1 Collection of data

First step is data collection such as feed flows, feed components and temperature of each stream in each unit, which are significant for calculation of information management system "Exaquantum". For heating value constant, it can be retrieved from references.

3.1.2 Planning of the energy diagram "plant wide energy"

An energy calculation programme for each process in gas separation plant is created and plant wide energy is designed to generate the process flow diagram in Microsoft Excel.

3.1.3 Calculation of total heating value

Total heating value can be calculated by

$$\text{HHV gas mixture} = \sum y_i HHV_i \qquad (3.1)$$

Where HHV gas mixture is total heating value of gas mixture.

y_i is molar ratio of gas.

HHV_i is heating value of gas mixture.

3.1.4 Calculation of duty heat exchanger

3.1.4.1 Calculation of heat transfer rate

Heat transfer rate can be calculated by replacing the heat transfer coefficient (h) with the overall heat transfer coefficient (U). ΔT may vary from any positions inside the duty of heat exchanger. Thus, this equation can be written as

$$Q = UA\Delta T_m \qquad (3.2)$$

Where Q is heat transfer rate (Watt (W) or btu/s).

U is overall heat transfer coefficient (W/m^2K).

A is total surface area for heat exchange (m^2).

ΔT_m is log mean temperature difference (LMTD) (K).

3.1.4.2 Calculation of log mean temperature difference (LMTD)

Generally, inside the duty heat exchanger, the temperature of fluid is not constant. The temperature of hot and cold fluid can reduce and increase exponentially. Therefore, the log mean temperature difference (LMTD) can be solved by the equation 2.4, depending on types of fluid according to chapter II (section 2.2.2).

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln(\Delta T_1/\Delta T_2)} \quad (2.4)$$

where ΔT_1 is the difference of temperature in (K).

ΔT_2 is the difference of temperature out (K).

When the temperatue in of duty heat exchanger is x °C and temperatue out is y °C., c_p can be solved from the interpolation of this formula $(\frac{x+y}{2})$ °C according to Table 3.1.

Table 3.1 c_p and density from simulation of hot oil utility at various temeratures*

Temperature (°C)	Density (kg/m^3)	c_p (J/K·g)
0	875	1.182
20	863	1.882
50	845	1.991
150	784	2.355
200	754	2.538
250	724	2.72
300	694	2.902
310	688	2.938
340	669	3.048

** It is a hypothetical component that has molecular weight of 400, nomal boiling point 2,380 °C and ideal liquid density 878 kg/m^3.*

When the feed flow equals to $\dot{V}$ m^3/h, the mass flow can be calculated by:

$$\rho = \frac{\dot{m}}{\dot{V}} \quad (3.3)$$

where ρ is density (kg/m^3).
$\dot{m}$ is mass flow rate (kg/h).
$\dot{V}$ is volumetric flow rate (m^3/h).

so

$$\dot{m} = \dot{V} \times \rho \tag{3.4}$$

Substituting the mass flow rate obtained from equation 3.4 into equation 3.5 to calculate heat transfer rate of duty heat exchanger ($\dot{Q}$)

$$\dot{Q} = \dot{m}c_p\Delta T \tag{3.5}$$

Thus, UA can also be calculated when the heat transfer rate of duty heat exchanger ($\dot{Q}$) is known.

Due to the direction of fluid inside the duty heat exchanger flowing in the parallel, log mean temperature difference (LMTD) can be solved by:

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln(\Delta T_1/\Delta T_2)} \tag{2.4}$$

When finding ΔT_m, UA can be solved by:

$$UA = \frac{\dot{Q}}{\Delta T_m} \tag{3.6}$$

And when comparing with UA_{design}

$$\Delta T_{m,design} = \frac{(\Delta T_{1,design} - \Delta T_{2,design})}{\ln(\Delta T_{1,design}/\Delta T_{2,design})} \tag{3.7}$$

When the $\dot{Q}_{design}$ is 88.6 MW.

$$UA_{design} = \frac{\dot{Q}_{design}}{\Delta T_{m,design}} \tag{3.8}$$

3.1.5 Calculation of heat exchanger efficiency can be calculated by

$$\% \, Efficiency = \frac{\mathrm{UA}}{\mathrm{UA}_{\mathrm{design}}} \times 100 \qquad (3.9)$$

3.1.6 Improvement of the programme in accordance with its suitability

3.1.7 Delivery of handbooks/user guide for this programme to demonstrate the energy diagram

3.2 Simulation of an energy system model for Rayong gas separation plant

Modeling the energy system of waste heat recovery unit and hot oil utility in the gas separation plant unit 6 by Aspen Hysys is divided into 5 steps.

1) Evaluate the process flow diagram of waste heat recovery unit

2) Model the waste heat recovery unit from the process flow diagram using the information from DCS monitor and plant wide energy map

3) Model user loop that consists of hight temeperature loop and low temperature loop

4) Create the reclycle chains that one of the chain is being bypassed and another is reclycled through 1st, 2nd and 3rd waste heat furnace

5) Improve the accuracy of simulated information

3.3 Optimization of an efficiency of the heating exchange

3.3.1 Optimization plan

Originally, hot oil in gas separation plant unit 5 and gas separation plant unit 6 is independent. This project plans to reduce fuel consumption using the remaining exhaust gas from the onshore compressor station (OCS), which is a station that increases the pressure of sale gas for transporting to the power plant, to heat hot oil in gas seperation plant unit 5. Then, this hot oil is sent to gas seperation plant unit 6 to use as heat transfer fluid instead of hot oil heated by low pressure fuel (fuel used in supplementary burner that consume excessively energy in waste heat recovery unit). All of the foregoing are the ways to increase an efficiency of the heating exchange of hot oil utiliity and waste heat recovery unit.

3.3.2 Estimation of operating expenses

The operating expanses is divided into 13 parts.

1) Engineering work
2) Piping work
3) Civil & steel structure work
4) Electrical work
5) Instrument work
6) Scaffolding work
7) Pipe marking
8) Commissioning work
9) Mobilization work
10) Project & safety managemant
11) Insurance
12) Bond & premium fee
13) Over head & profit

3.3.3 Calculation of the annual cost saving

$$\text{Cost saving per year} = \text{energy saving} \times \text{fuel cost} \times \text{WHRU eff} \times 24\ \text{hr} \times 365\ \text{day} \tag{3.10}$$

3.3.4 Calculation of %IRR

Calculation of the %IRR from operating expenses and the annual cost savings are done by Microsoft Excel.

CHAPTER IV

RESULTS AND DISCUSSION

Preparation of plant wide energy map for optimization of the hot oil utility and the waste heat recovery unit can be divided into 3 steps as followed

- Generation of the overall plant wide energy map of Rayong gas separation plant
- Model of energy systems used in waste heat recovery unit using Aspen Hysys program
- Optimization of hot oil utility and waste heat recovery unit

Data of case study and calculation examples are shown in Appendix.

4.1. Generation of the overall plant wide energy map of Rayong gas separation plant

4.1.1 Calculation of the overall plant wide energy map

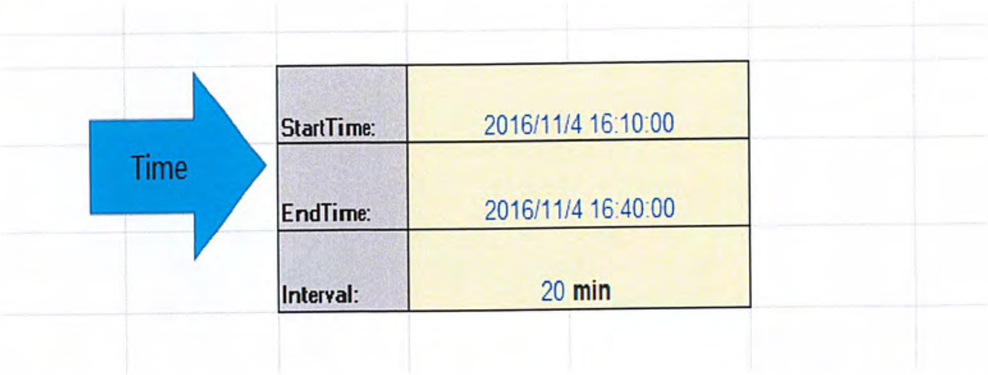
The first part of program is a calculation showing the energy consumption of each unit. To be consistent with the design process, the following procedures and calculations were performed. The user must enter the information in the yellow cell of the program page, as shown in Figure 4.1., with the following information.

4.1.1.1 Data Input

1) Date and time at initial of the time required

2) Date and time at final of the time required

3) Time required for data acquisition

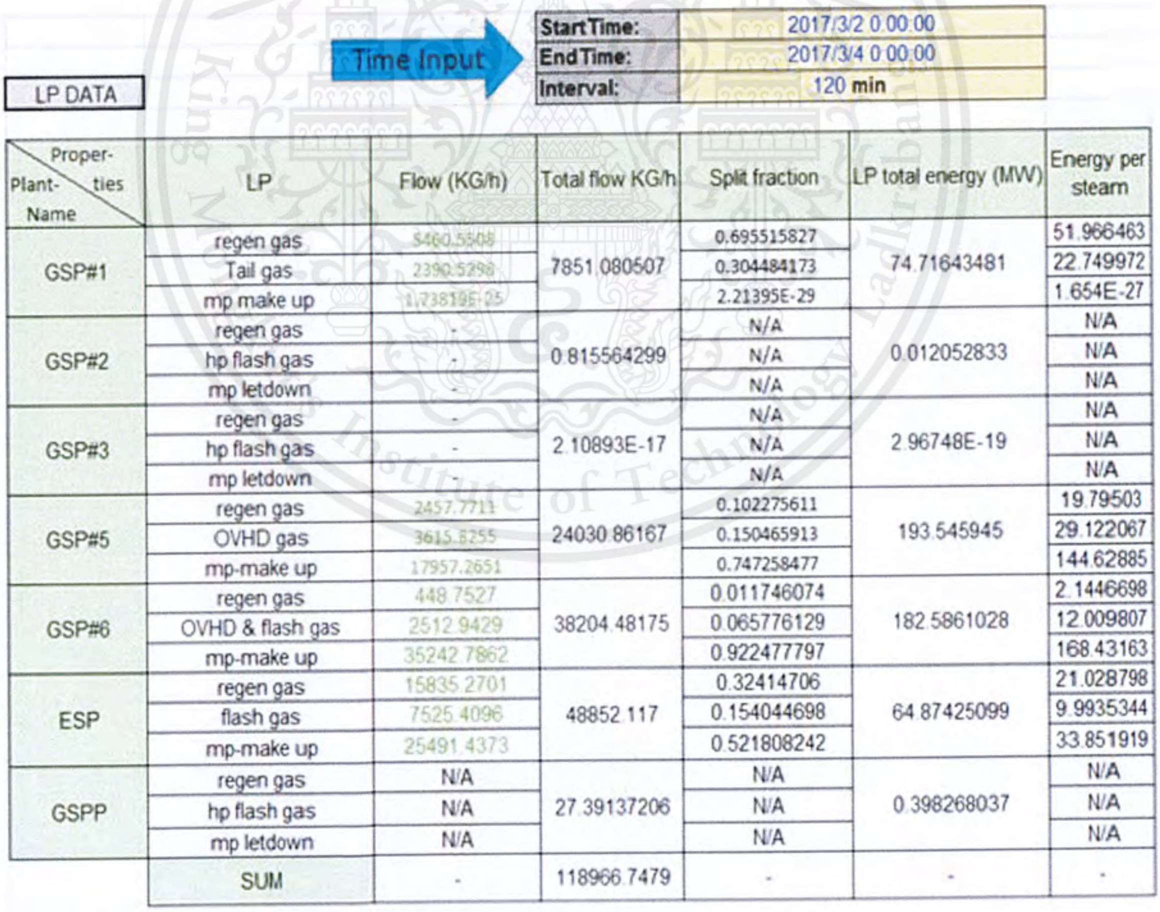


StartTime:	2016/11/4 16:10:00
EndTime:	2016/11/4 16:40:00
Interval:	20 **min**

Figure 4.1 Date and time input table for overview energy system in Rayong gas separation plant

4.1.2 Calculation process

The table displays the calculated results at the given time interval: energy input in each unit, energy used in each unit and energy efficiency of each unit is shown in Figure 4.2.



StartTime:	2017/3/2 0:00:00
EndTime:	2017/3/4 0:00:00
Interval:	120 **min**

Plant-Name / Properties	LP	Flow (KG/h)	Total flow KG/h	Split fraction	LP total energy (MW)	Energy per steam
GSP#1	regen gas	5460.5508	7851.080507	0.695515827	74.71643481	51.966463
	Tail gas	2390.5298		0.304484173		22.749972
	mp make up	1.73819E-25		2.21395E-29		1.654E-27
GSP#2	regen gas	-	0.815564299	N/A	0.012052833	N/A
	hp flash gas	-		N/A		N/A
	mp letdown	-		N/A		N/A
GSP#3	regen gas	-	2.10893E-17	N/A	2.96748E-19	N/A
	hp flash gas	-		N/A		N/A
	mp letdown	-		N/A		N/A
GSP#5	regen gas	2457.7711	24030.86167	0.102275611	193.545945	19.79503
	OVHD gas	3615.8255		0.150465913		29.122067
	mp-make up	17957.2651		0.747258477		144.62885
GSP#6	regen gas	448.7527	38204.48175	0.011746074	182.5861028	2.1446698
	OVHD & flash gas	2512.9429		0.065776129		12.009807
	mp-make up	35242.7862		0.922477797		168.43163
ESP	regen gas	15835.2701	48852.117	0.32414706	64.87425099	21.028798
	flash gas	7525.4096		0.154044698		9.9935344
	mp-make up	25491.4373		0.521808242		33.851919
GSPP	regen gas	N/A	27.39137206	N/A	0.398268037	N/A
	hp flash gas	N/A		N/A		N/A
	mp letdown	N/A		N/A		N/A
	SUM	-	118966.7479	-	-	-

Figure 4.2 Table of overview energy system in the Rayong gas separation plant results

4.1.3 Plant wide energy map

Plant wide energy map of hot oil, waste heat recovery unit (WHRU) and heat exchanger used in the Rayong gas separation plant in units 1 to 6 and the ethane separation plant are shown in Figures 4.3 to 4.7. Blue and yellow lines represent energy generated from moderate and low pressure fuel, respectively. Red line is the released energy from stack and flare.

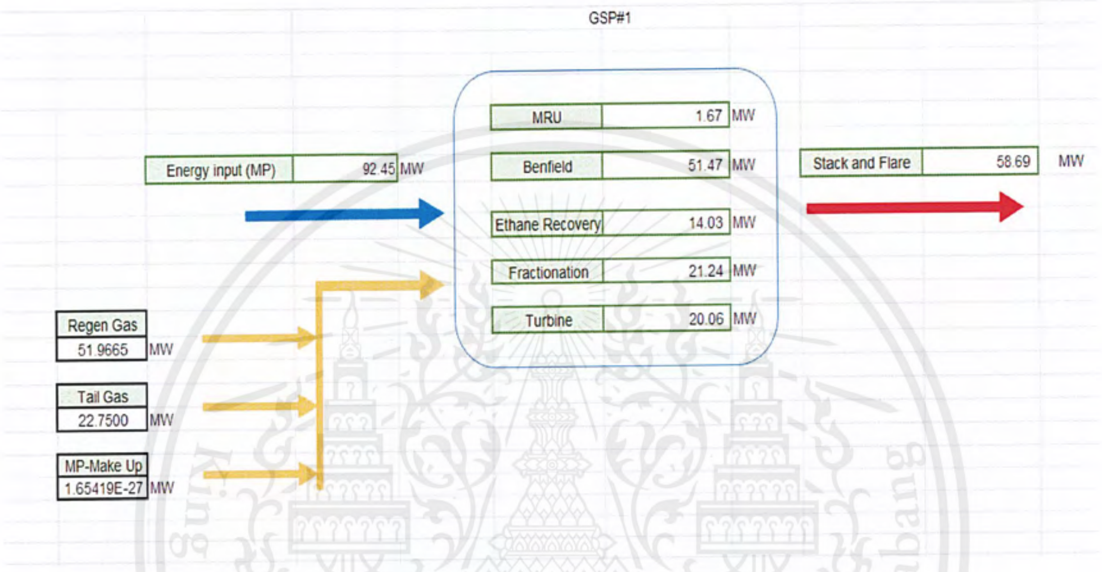


Figure 4.3 Plant wide energy map system In Rayong gas separation plant unit 1

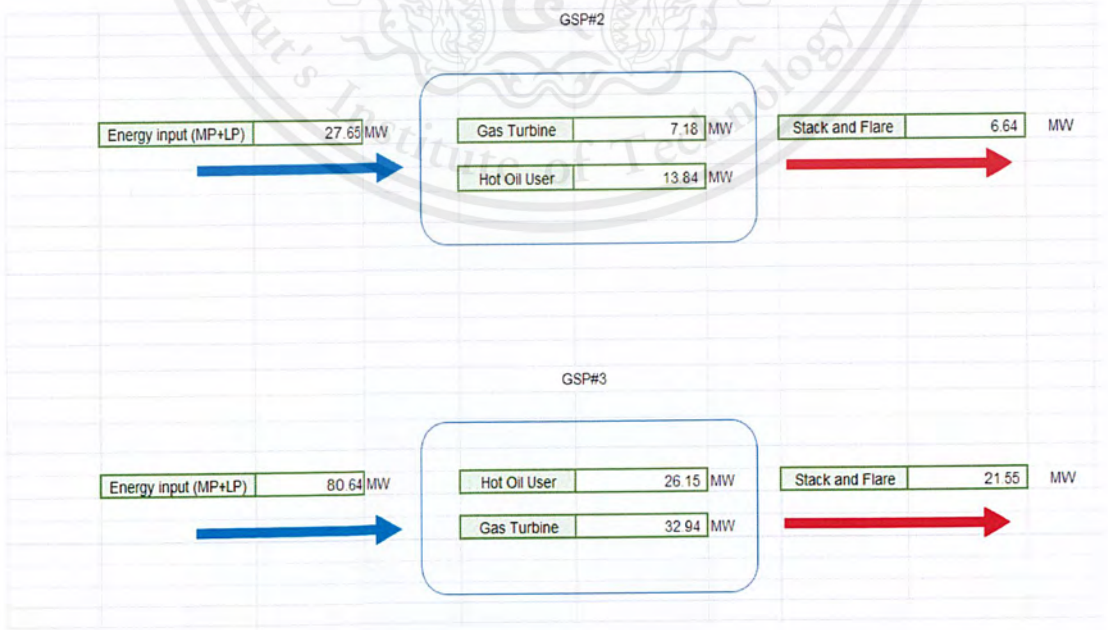


Figure 4.4 Plant wide energy map system in Rayong gas separation plant unit 2 (top) and 3 (bottom)

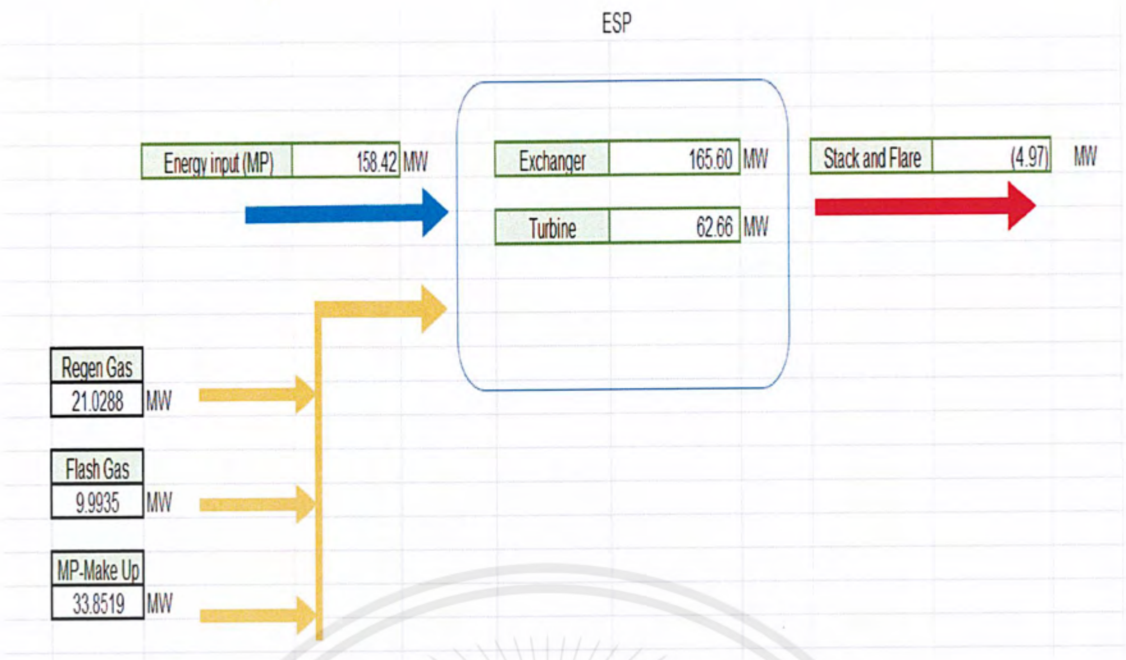


Figure 4.5 Plant wide energy map system in ethane separation plant at Rayong gas separation plant

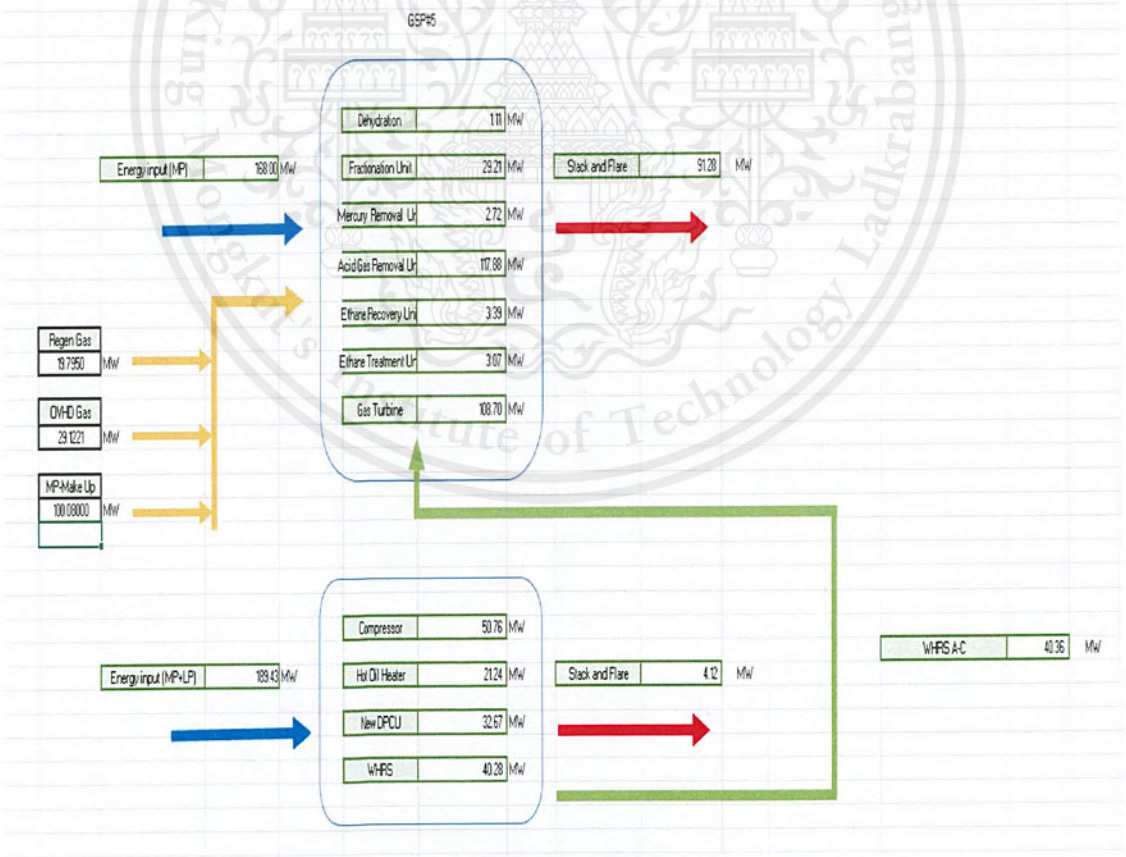


Figure 4.6 Plant wide energy map system in Rayong gas separation plant unit 5 (top) and gas pipeline processing plant (bottom)

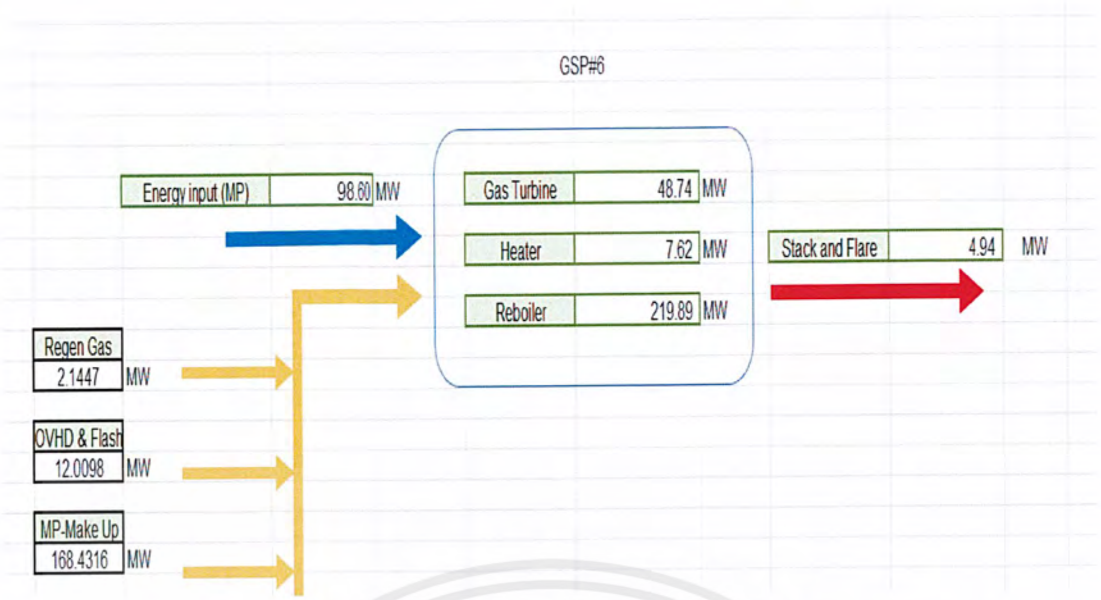


Figure 4.7 Plant wide energy map system in Rayong gas separation plant unit 6

After calculation, it was found that plant wide energy map is very accurate to get a large data from overall plant and easily used to identify error in plant. The data obtained from this part were used to optimize by simulation program in the next section.

4.2 Model of energy systems used in waste heat recovery unit using Aspen Hysys

4.2.1 Components of the waste heat recovery unit model can be divided into 3 parts:

1) Waste heat furnace

Gas turbine uses moderate pressure fuel (MP-Fuel) as fuel and sends exhaust to generator to generate electricity, which has an exhaust temperature about 450°C. This exhaust gas will be delivered to combine with low pressure fuel (LP-Fuel) at supplementary burner to provide sufficient heat to exchange with hot oil to 270°C, as shown in the Figure 4.8.

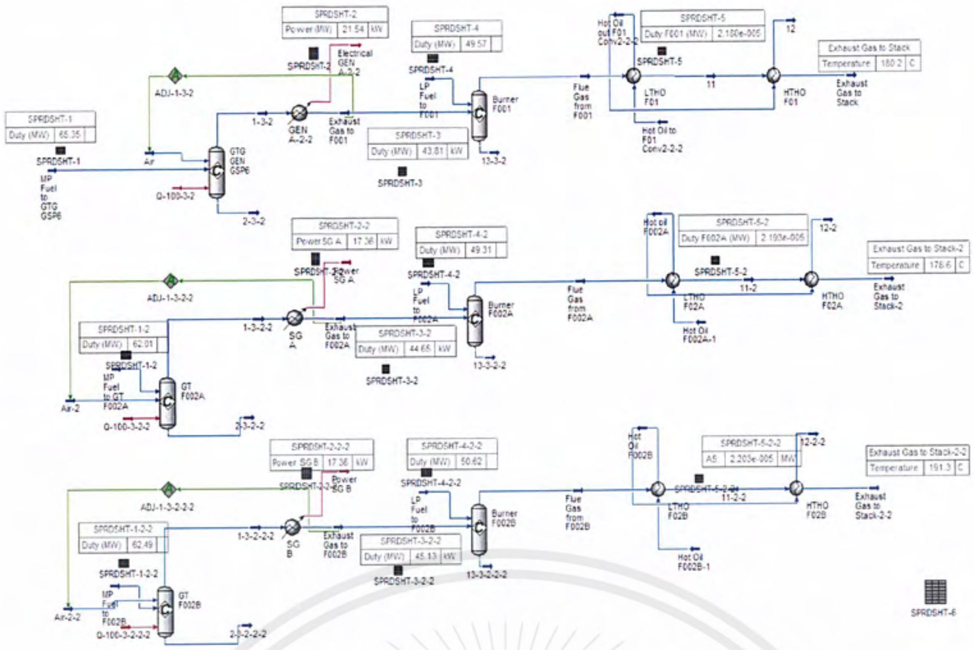


Figure 4.8 Simulation of waste heat furnace of Rayong gas separation plant unit 6

2) High temperature loop hot oil user

Users that used 270°C-hot oil (High temperature) in the heat exchanger consists of de-ethanizer reboiler, LPG recovery column reboiler, de-propanizer reboiler and regeneration gas heater as shown in Figure 4.9.

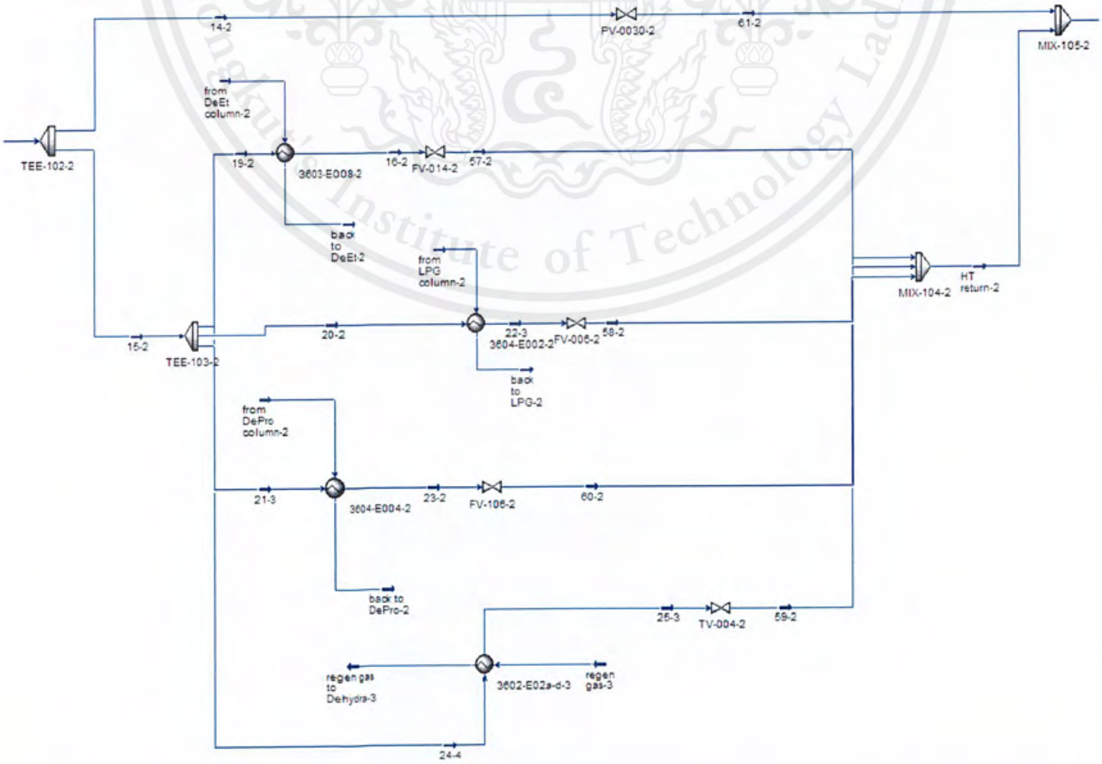


Figure 4.9 Simulation of high temperature loop of Rayong gas separation plant unit 6

3) Low temperature loop hot oil user

Low temperature loop hot oil user uses hot oil at 170°C, which is produced from the mixture of hot oil released from waste heat furnace. These users are amine stripper (amine reboiler)-train 1, amine stripper (amine reboiler)–train 2, feed gas heater and de-methanizer reboiler as shown in Figure 4.10.

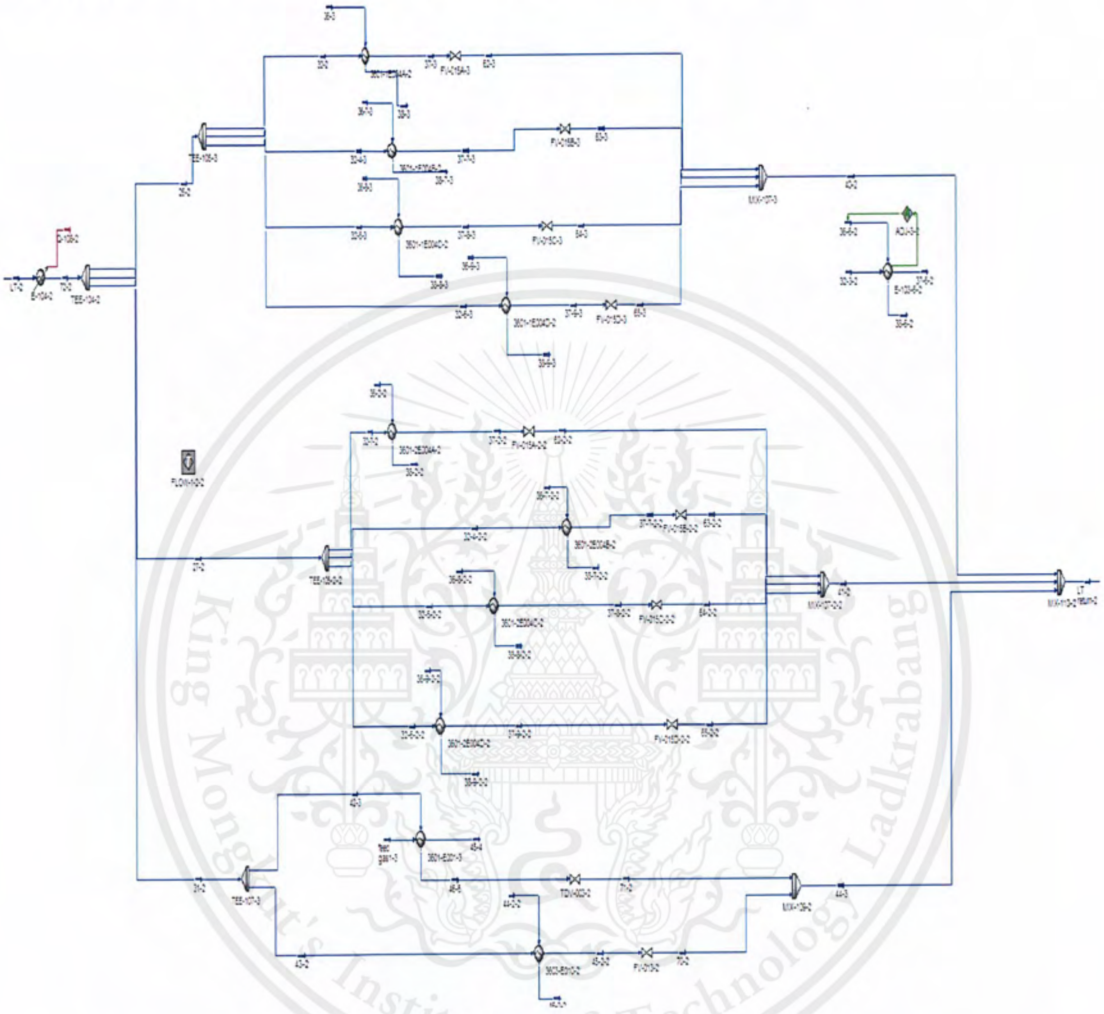


Figure 4.10 Simulation of low temperature loop of Rayong gas separation plant unit 6

Finished model of waste heat recovery unit in Rayong gas separation unit 6 by using Aspen Hysys program is shown in the Figure 4.11. The flow rate of hot oil through the user, through the furnace to heat waste furnace and by pass to Low temperature loop are 6000, 3000 and 3000 m^3/h, respectively.

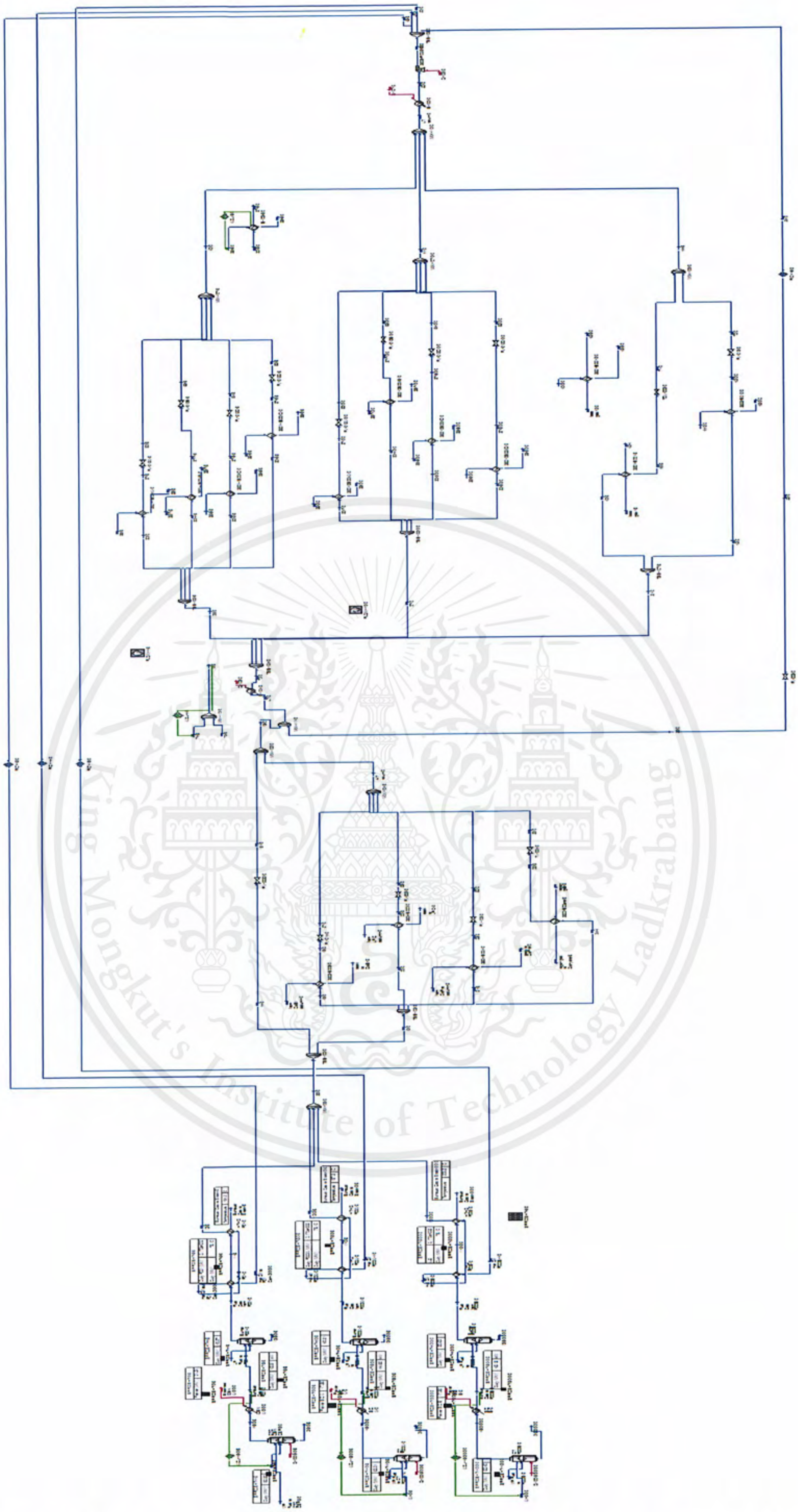
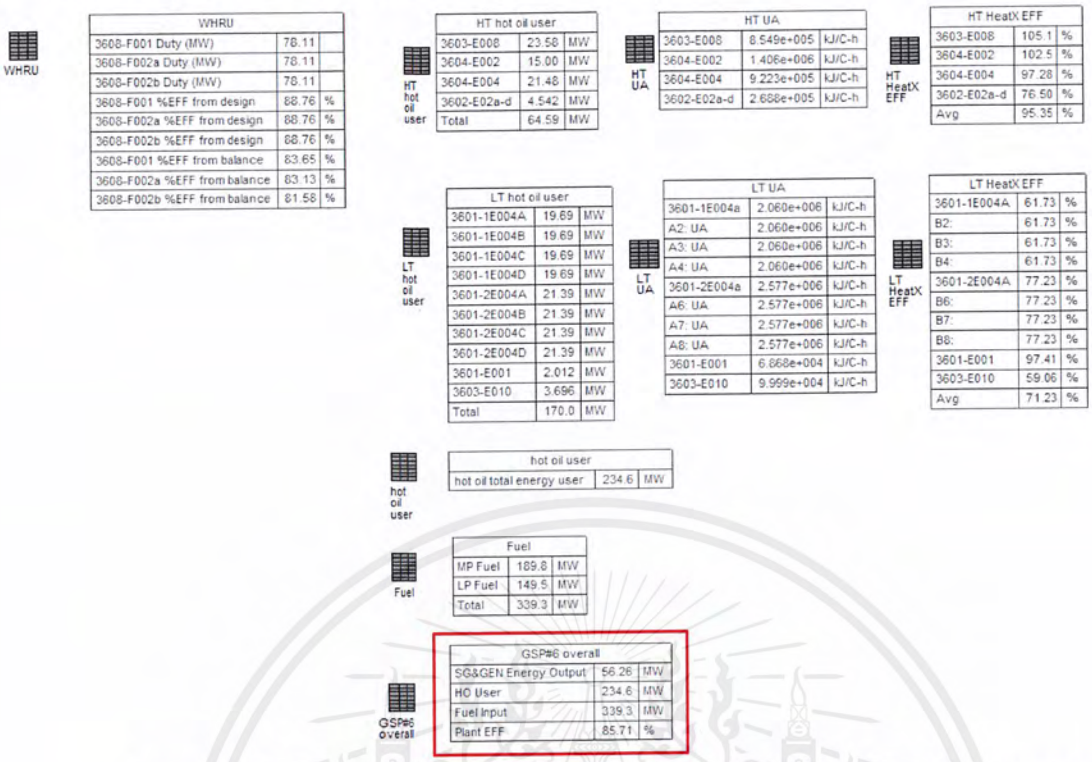


Figure 4.11 Simulation of waste heat recovery unit of Rayong gas separation plant unit 6

4.2.2 Comparison of the data obtained from program



WHRU		
3608-F001 Duty (MW)	78.11	
3608-F002a Duty (MW)	78.11	
3608-F002b Duty (MW)	78.11	
3608-F001 %EFF from design	88.76	%
3608-F002a %EFF from design	88.76	%
3608-F002b %EFF from design	88.76	%
3608-F001 %EFF from balance	83.65	%
3608-F002a %EFF from balance	83.13	%
3608-F002b %EFF from balance	81.58	%

HT hot oil user		
3603-E008	23.58	MW
3604-E002	15.00	MW
3604-E004	21.48	MW
3602-E02a-d	4.542	MW
Total	64.59	MW

HT UA		
3603-E008	8.549e+005	kJ/C-h
3604-E002	1.406e+006	kJ/C-h
3604-E004	9.223e+005	kJ/C-h
3602-E02a-d	2.688e+005	kJ/C-h

HT HeatX EFF		
3603-E008	105.1	%
3604-E002	102.5	%
3604-E004	97.28	%
3602-E02a-d	76.50	%
Avg	95.35	%

LT hot oil user		
3601-1E004A	19.69	MW
3601-1E004B	19.69	MW
3601-1E004C	19.69	MW
3601-1E004D	19.69	MW
3601-2E004A	21.39	MW
3601-2E004B	21.39	MW
3601-2E004C	21.39	MW
3601-2E004D	21.39	MW
3601-E001	2.012	MW
3603-E010	3.696	MW
Total	170.0	MW

LT UA		
3601-1E004a	2.060e+006	kJ/C-h
A2: UA	2.060e+006	kJ/C-h
A3: UA	2.060e+006	kJ/C-h
A4: UA	2.060e+006	kJ/C-h
3601-2E004a	2.577e+006	kJ/C-h
A6: UA	2.577e+006	kJ/C-h
A7: UA	2.577e+006	kJ/C-h
A8: UA	2.577e+006	kJ/C-h
3601-E001	6.868e+004	kJ/C-h
3603-E010	9.999e+004	kJ/C-h

LT HeatX EFF		
3601-1E004A	61.73	%
B2:	61.73	%
B3:	61.73	%
B4:	61.73	%
3601-2E004A	77.23	%
B6:	77.23	%
B7:	77.23	%
B8:	77.23	%
3601-E001	97.41	%
3603-E010	59.06	%
Avg	71.23	%

hot oil user		
hot oil total energy user	234.6	MW

Fuel		
MP Fuel	189.8	MW
LP Fuel	149.5	MW
Total	339.3	MW

GSP#6 overall		
SG&GEN Energy Output	56.26	MW
HO User	234.6	MW
Fuel Input	339.3	MW
Plant EFF	85.71	%

Figure 4.12 Overall data table of waste heat recovery unit from Aspen Hysys program

After comparison of the data obtained from Aspen Hysys, it was found that total power consumption is about 234.6 MW, 69.14% of the power generated by fuel (339.3 MW.).

Table 4.1 Comparison of UA values obtained from simulation and the design and the efficiency of the heat exchanger from simulation plant high temperature loop

User	UA (simulation), kJ/°C-h	UA (design), kJ/°C-h	%Efficiency
Deethanizer reboiler	8.549×10^5	8.985×10^5	105.1
LPG recovery column reboiler,	1.406×10^6	1.441×10^6	102.5
Depropanizer reboiler	9.223×10^5	8.972×10^5	97.28
Regeneration gas heater	2.688×10^5	2.056×10^5	76.50

Table 4.2 Comparison of UA values obtained from simulation and the design and the efficiency of the heat exchanger from simulation plant low temperature loop

User	UA (simulation), kJ/°C-h	UA (design), kJ/°C-h	%Efficiency
Feed gas heater	6.868×10^4	6.690×10^4	97.41
Demethanizer reboiler	9.999×10^4	5.906×10^4	59.06
Amine stripper (amine reboiler)-train 1	8.240×10^6	5.087×10^6	61.73
Amine stripper (amine reboiler)-train 2	1.031×10^7	7.966×10^6	77.26

The result from high temperature loop is quite larger than low temperature loop.

4.3 Optimization of hot oil utility and waste heat recovery unit

1) Optimization of hot oil utility and waste heat recovery unit

Aspen Hysys program can improve an efficiency of waste heat recovery unit. Exhaust gas discharged in stack and flare in gas pipeline processing plant (GPPP) are used to heat hot oil from gas separation plant unit 5 from 115 °C to 270 °C at the rate of 800 m^3/h. At this rate, it is sufficient to exchange heat with fluid in de-propanizer and LPG-column reboiler of gas separation plant unit 6 (see in Figure 4.13.).

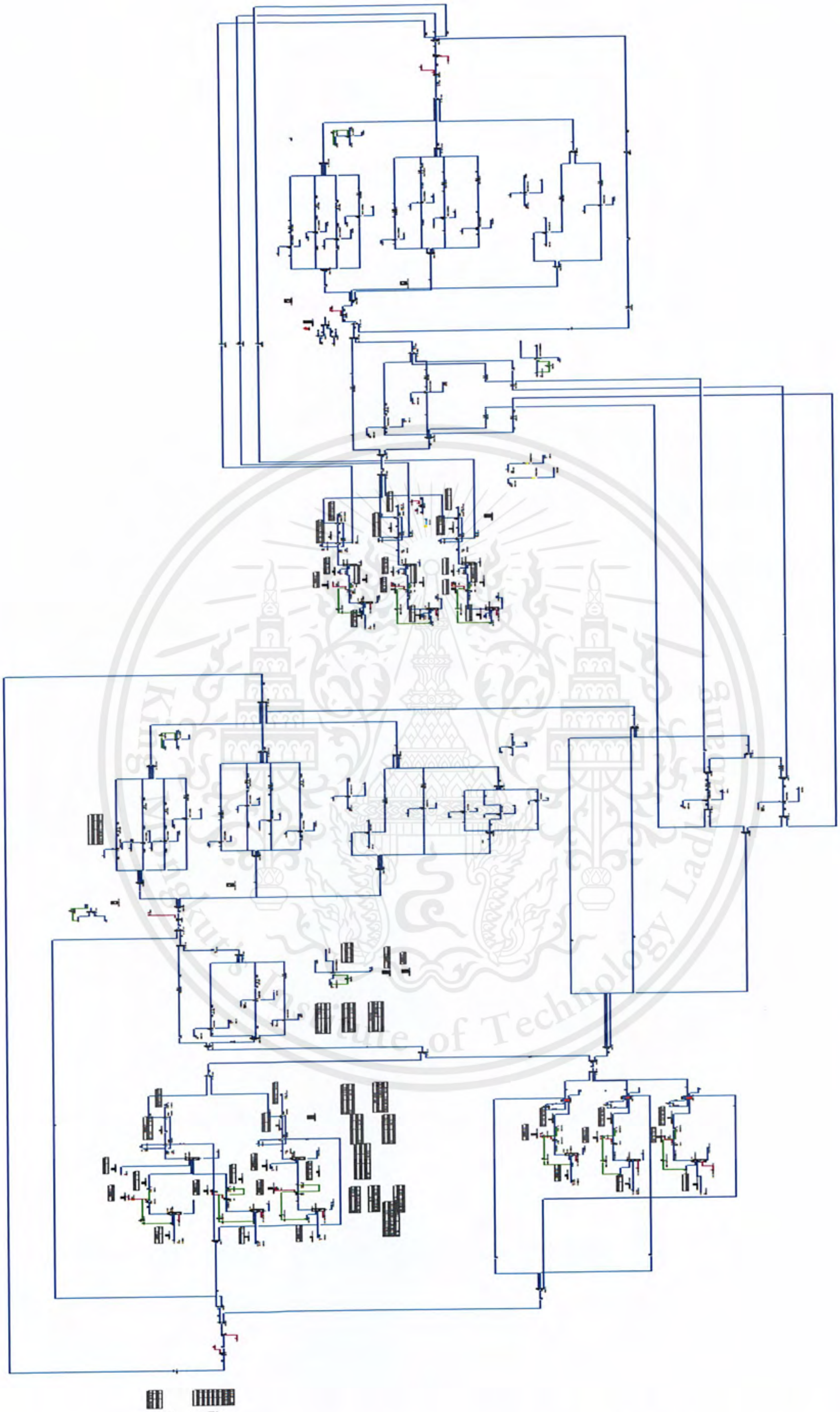


Figure 4.13 Optimization of Rayong gas separation plant unit 5, 6 and gas pipeline processing plant

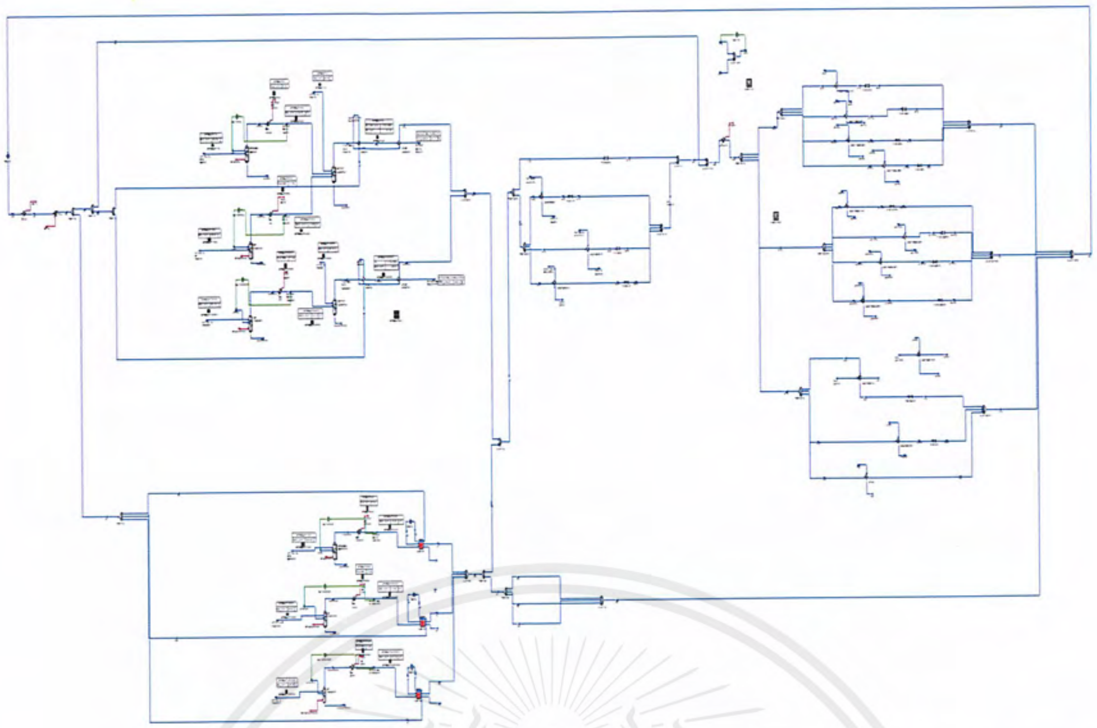


Figure 4.14 Optimization of Rayong gas separation plant unit 5 connect with gas pipeline processing plant to reduce load of waste heat fernace in gas separation plant unit 5

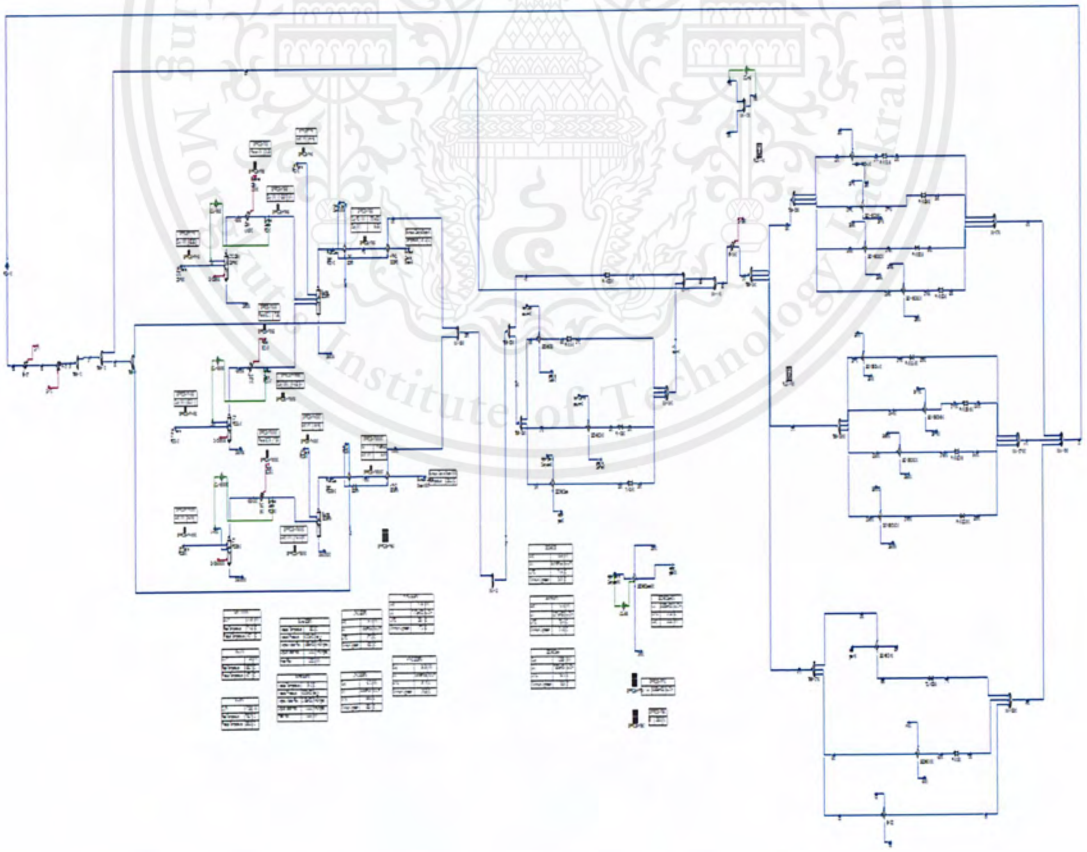


Figure 4.15 Optimization of Rayong gas separation plant unit 5

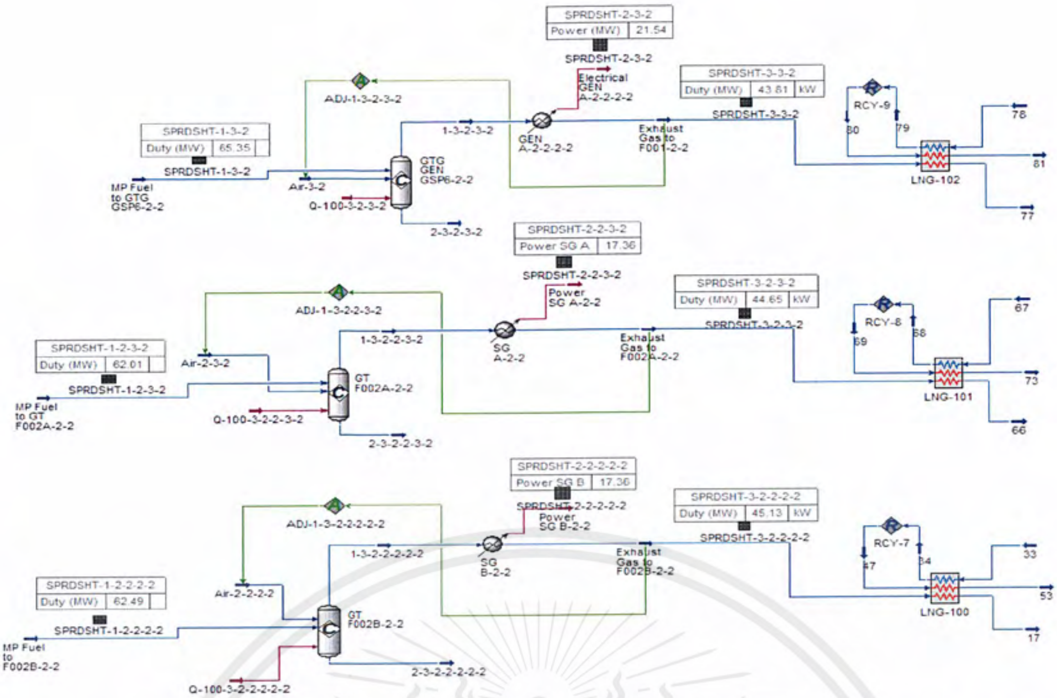


Figure 4.16 Simulation of waste heat furnace of gas pipeline processing plant at Rayong gas separation plant unit 5

2) Result of fuel savings

Total energy saving is 44.46 MW. The furnace has an efficiency about 0.815, so the power from fuel saving is 44.46/0.815 = 54.55 MW and low pressure fuel (LP Fuel) saving is 4894.87 Nm^3/h.

3) Result of cost savings per year

Cost saving is 222,021,001.2 Baht/year.

4) Result of %IRR 5 years project duration calculated.

%IRR = 113.5%

After calculation, it is able to reduce the power consumption of 44.46 MW, which save 222,021,001.2 Baht/year. This project is worth to invest because the %IRR of 5 years duration is 113.5%, which is very high.

CHAPTER V

CONCLUSION AND SEGGESTIONS

5.1 Conclusion

The overall plant wide energy map in Rayong gas separation plant can be used to identify excessively energy consumption in plant.

For optimization, the total energy saving from waste heat recovery unit is 44.46 MW and thus low pressure fuel (LP Fuel) saving is 4894.87 Nm^3/h. In economics, cost saving from fuel is 222,021,001.2 Baht/ year., %IRR of 5 years project duration is 113.5 %. And breakeven point in 29.8 month.

5.2 Suggestions

Optimization of hot oil utility and waste heat recovery unit plant model used in gas separation plant unit 6 can be used as a model to improve the efficient of energy reduction for other heat exchange units and apply to other plants. Because in every plant has enough non-beneficial heat energy, which lead to a worthwhile investment. If this project is made in real situation, It is necessary to provide the waste heat recovery unit in order to calculate the detail of heat exchanger instead of shortcut of heat exchanger simulation.

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APPENDIX

APPENDIX A

RAW DATA

Table A.1 The components of natural gas

Component	Mole fraction
Nitrogen	0.023
Methane	0.887
Ethane	0.056
Propane	0.021
iso-Butane	0.003
n-Butane	0.006
Pentane mix*	0.004
Total	1.000

Table A.2 The heating value of natural gas

Component	Heating value	
	btu/ft^3	MJ/m^3
Nitrogen	0.0	0.0
Methane	1009.7	37.7
Ethane	1768.8	66.0
Propane	2517.4	94.0
iso-Butane	3252.7	121.4
n-Butane	3262.1	121.8
Pentane mix*	4380.4	163.5

* Including 0.001 n-C_5, 0.001 I-C_5 and 0.002 N-C_5

Table A.3 Design value of waste heat furnace

No. item	Temperature (°C)		Density	T_{avg}	C_p	Flow rate	Q_{design}
	T_{in}	T_{out}	(kg/m^3)	(°C)	(kJ/kg.K)	(kg/s)	(MW)
3608F001	130	270	712.02	200	2.417	249.30	84.358
3608F002A	130	270	712.02	200	2.417	249.30	84.358
3608F002B	130	270	712.02	200	2.417	249.30	84.358

Table A.4 Design value of modelated pressure fuel

Component	LHV (Btu/Scf)	Mole (%)	Mole fraction
C1	909.4	87.99	0.8799
C2	1618.7	2.98	0.0298
C3	2314.9	1.22	0.0122
iC4	3000.4	0.23	0.0023
nC4	3010.8	0.19	0.0019
iC5	3699.0	0.04	0.0004
nC5	3706.9	0.03	0.0003
C6	4403.8	0.02	0.0002
C7	5100.0	0.00	0.0000
N2	0.0	1.71	0.0171
CO2	0.0	5.59	0.0559

Table A.5 Design value of low pressure fuel

Component	LHV (Btu/Scf)	Mole (%)	Mole fraction
C1	909.4	81.16	0.8116
C2	1618.7	1.25	0.0125
C3	2314.9	0.59	0.0059
iC4	3000.4	0.14	0.0014
nC4	3010.8	0.14	0.0014
iC5	3699.0	0.00	0.0000
nC5	3706.9	0.09	0.0009
C6	4403.8	0.04	0.0004
C7	5100.0	0.02	0.0002
N2	0.0	1.04	0.0104
CO2	0.0	14.24	0.1424

Table A.6 Design value of gas turbine in gas separation plant unit 6

Service	Flow rate		Q_{fuel}	Power generate	$Q_{exhaust\ gas}$	%EFF design	%EFF design
	(Nm^3/h)	(Scfd)	(MW)	(MW)	(MW)		Com,Gen
SCGTA	6140.18	5498501.6	59.928	18.00	41.928	91.629	30.036
SCGTB	6140.18	5498501.6	59.928	18.00	41.928	92.336	30.036
GTG	6140.18	5498501.6	59.928	22.73	37.198	97.377	37.929

Table A.7 Design value of hot oil user in waste heat recovery unit

Unit			m	c_{pg}	c_p	T_{in}	T_{out}	T_{avg}	Q_{design}
			(Kg/h)	(kJ/kg.K)	(kJ/kg.K)	(°C)	(°C)	(°C)	(MW)
Hot Oil User	3601-E-001	Feed Gas Heater	51882	2.585	2.649	270	170	220	3.726
	3601-1-E-004A-D	Amine stripper reboiler#1	3290782	2.277	2.425	170	130	150	83.264
	3601-2-E-004A-D	Amine stripper reboiler#2	3290782	2.277	2.425	170	130	150	83.264
	3602-E-002A-D	Regen gas heater	59520	2.585	2.649	270	170	220	4.274
	3603-E-008	DeE reboiler	380843	2.585	2.584	270	170	220	27.349
	3603-E-010	DeM reboiler	231228	2.277	2.316	170	130	150	5.851
	3604-E-002	LPG column reboiler	287173	2.585	2.586	270	170	220	20.622
	3604-E-004	DeP reboiler	406920	2.585	2.586	270	170	220	29.221

APPENDIX B

EXAMPLE OF CALCULATION

1. Power comsumption calculation

Total heating value calculation

$$\text{HHV gas mixture} = \sum y_i HHV_i \qquad (3.1)$$

$$\begin{aligned}\text{HHV gas mixture} = {} & (0.023 \times 0.00\ \text{MJ/m}^3) + (0.887 \times 37.694\ \text{MJ/m}^3) + \\ & (0.056 \times 66.032\ \text{MJ/m}^3) + (0.021 \times 93.972\ \text{MJ/m}^3) + \\ & (0.003 \times 121.426\ \text{MJ/m}^3) + (0.006 \times 121.426\text{MJ/m}^3) \\ & + (0.004 \times 163.521\text{MJ/m}^3)\end{aligned}$$

$$\text{HHV gas mixture} = 40.855\ \text{MJ/m}^3$$

Power comsumption

$$\begin{aligned}\text{HHVgasmixture} &= 40.855\ \frac{\text{MW}\cdot\text{s}}{\text{m}^3} \times 4{,}200\ \frac{\text{m}^3}{3600\ \text{s}} \\ &= 47.664\ \text{MW}\end{aligned}$$

2. Duty heat exchanger calculation

c_p calculation form Interpolation

$$\begin{aligned}C_{p\,(149.1^\circ\text{C})} &= 1.991 + \frac{(2.355-1.991)}{(150-50)} \times (149.1\text{-}50.0) \\ &= 2.352\ \text{kJ/kg.K}\end{aligned}$$

Mass flow rate calculation

$$\begin{aligned}\dot{m} &= \dot{V} \times \rho \qquad (3.4) \\ &= 6{,}250\ \text{m}^3\text{/h} \times 878\ \text{kg/m}^3 \\ &= 5487500\ \text{kg/h}\end{aligned}$$

Duty of heat exchanger

$$\dot{Q} = \dot{m}c_p\Delta T \qquad (3.5)$$

$$= 5487500 \text{ kg/h} \times 2.352 \text{ kJ/kg.K} \times (174.2\ ^\circ\text{C} - 124\ ^\circ\text{C})$$

$$= 647911320 \text{ kJ/h}$$

$$= 179975.367 \text{ kW} = 179.975 \text{ MW}$$

3. Efficency heat exchanger calculation

log mean temperature difference calculation

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln(\Delta T_1/\Delta T_2)} \qquad (2.4)$$

$$= \frac{(74.66-9)\text{K}}{\ln{(74.66/9)}}$$

$$= 31.03 \text{ K}$$

UA calculation

$$UA = \frac{\dot{Q}}{\Delta T_m} \qquad (3.6)$$

$$= \frac{179.975 \text{ MW}}{31.03 \text{ K}}$$

$$= 5.8 \text{ MW/K}$$

UA Design calculation

$$\Delta T_{m,design} = \frac{(\Delta T_{1,design} - \Delta T_{2,design})}{\ln(\Delta T_{1,design}/\Delta T_{2,design})}$$

(3.7)

$$= \frac{(48.1\text{K}-8.1\text{ K})}{\ln(48.1\text{K}/8.1\text{K})}$$

$$= 22.454\text{ K}$$

$$\text{UA}_{\text{design}} = \frac{\dot{Q}_{\text{design}}}{\Delta T_{\text{m,design}}} \tag{3.8}$$

$$= \frac{88.6\text{ MW}}{22.454\text{ K}}$$

$$= 3.946\text{ MW/K}$$

Efficency calculation

$$\%\text{ Efficiency} = \frac{\text{UA}}{\text{UA}_{\text{design}}} \times 100 \tag{3.9}$$

$$= \frac{5.8\text{ MW/K}}{3.946\text{ MW/K}} \times 100$$

$$= 146.98\ \%$$

4. the annual cost saving Calculation

$$\text{Cost saving per year} = \text{energy saving} \times \text{fuel cost} \times \text{WHRU eff} \times 24\text{ hr} \times 365\text{ day} \tag{3.10}$$

$$= (44.46 \times 3.412) \times 205 \times 0.815 \times 24 \times 365$$

$$= 222{,}021{,}001.2\text{ Baht/year}$$

BIOGRAPHY

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Academic Background

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- 2014 – Present: Bachelor of Petrochemical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang

Working Experiences

- June 2017 – July 2017: Internship Program 2017 at Yamagata University, Japan
- August 2017 – November 2017: Co-operative Education 2017 at Rayong Gas Separation Plant, PTT Company Limited