CHAPTER III
PROCEDURE

This work has determined the exergetic efficiency of plant 2 of the Bangchak Refinery. There are two parallel plants in the Bangchak refinery. This work has determined the exergetic efficiency in each unit and waste heat boiler of the refinery to indicate the thermodynamic performance of the various sections of the plant. The analysis of major equipment with the lowest efficiency has been studied in order to determine possible improvements in the operation of such equipment.

3.1 Calculation Method for Physical Exergy

The Physical exergy (B_{ph}) of each process stream was obtained from the Provision II computer simulation program which calculates the physical exergy by ($H-T_o*S$). In order to define B_{ph} , it was necessary to specify the component and condition of each stream (temperature, pressure) in order for calculating the enthalpy and entropy of each stream. In addition, a suitable thermodynamic method is required to determine the correct value.

Provision II computer simulation program recommends a suitable method for such calculations. For the light hydrocarbon stream the Solve-Redlich-Kwong (SRK) thermodynamic method has chosen to define the physical properties. For the water and steam system the physical properties can be calculated by the SRK thermodynamic method which specifies a steam table option. And the Grayson-Streed method was selected to calculate the physical properties of light oil and heavy oil. In this method it will use Curl-Pitzer method to calculate liquid enthalpy and entropy.

In order to specify the components of each stream in the process the gas chromatography has been used to define the component of light hydrocarbons. And for the heavy hydrocarbon components it is difficult to determine the exact composition and these are specified by a distillation curve. The ASTM D86 , TBP and API gravity were used as input to specify such streams.

In the exergy report from PRO П program. There are 5 exergy functions which depend on the various applications of the user. The two significant outputs that used in this study are $B_{(EXS)}$ which is the exergy at the existing state of the stream and $B_{(EVS)}$ which is the exergy at the environmental state at T_0 and P_0. The use of $B_{(EXS)}$-$B_{(EVS)}$ has been determined to denote the exergy of each stream.

3.2 Calculation Method for Chemical Exergy

Szargut *et al.* (1988) defined the standard chemical exergy of organic and inorganic substances at reference temperature (298.15 K) and reference pressure (101.325 kPa). In order to find the chemical exergy of each stream, the mole percent of each components has to be determined. However for heavy oil a calculation of the chemical exergy cannot be made directly because the composition is not defined. Therefore the elemental analysis of organic compound C,H,O,N,S,and H_2O were used to estimate the chemical exergy from the formula.

$$B_{ch} = (C_l+LZ_w)\beta + (b_{ch}\, s-C_s)Z_s + b_{cha}\, Z_a + b_{chw}Z_w \quad (3.1)$$

$$= (C_f-9LZ_{H2})\beta + (b_{chs}-C_s)Z_s + b_{cha}Z_a + b_{chw}Z_w \quad (3.2)$$

where

C_f = gross calorific value of the moist fuel

C_l = net calorific value of the moist fuel

L = enthalpy of water vaporization

Z_{H2} = hydrogen mass fraction in moist fuel

Z_w = water mass fraction in moist fuel

Z_s = mass fraction of sulfur

Z_a = mass fraction of ash

B_{chs} = standard chemical exergy of sulfur

B_{cha} = standard chemical exergy of ash

B_{chw} = standard chemical exergy of water

$$\beta=1.041+0.1728\frac{Z_{H2}}{Z_c}+0.0432\frac{Z_{O2}}{Z_c}+0.2169\frac{Z_s}{Z_c}\left(1-2.028\frac{Z_{H2}}{Z_c}\right) \quad (3.3)$$

B_{ch}-C_s= 9683 kJ/kg.

<u>Example</u>

Crude oil has mass fraction of C (Z_c)=86.3, Z+=13.6, Z_{O2}=0.01, Z_n=0, Z_s=0.11, Z_{water}=0 and API gravity = 42.5, and heating value =46070.9 kJ/kg

$$\beta = 1.041+0.1728\frac{13.6}{86.3}+0.0432\frac{0.01}{86.3}+0.2169\frac{0.11}{86.3}\left(1-2.028\frac{13.6}{86.3}\right)$$

= 1.0675

B_{ch} = (46070.9+0)*1.0675+(9683*0.11)+(50*0)+0

= 50245 kJ/kg.

3.3 Calculation Formula

3.3.1 Exergetic Efficiency of Process

It can be determined from

$$\text{Exergetic efficiency} = \frac{\Delta B_{\text{useful change}} + \Delta B_{\text{mixing}} + B_{\text{credit}}}{\Delta B_{\text{driving}}} \quad (3.4)$$

where

$\Delta B_{\text{useful change}}$ = exergy change from feed to product

ΔB_{mixing} = change in exergy for separation

$\Delta B_{driving}$ = exergy change of all stream used to operate the process

B_{credit} = useful exergy deriving from process.

For some process the exergy efficiency is not convenient, an alternative measure of performance is degree of perfection (ηp)

$$\eta_p = \frac{\text{Exergy of useful product}}{\text{Feeding exergy}} = \frac{B_p + B_q + W_u}{B_p + B_{qf} + W_f} \quad (3.5)$$

where

B_p = useful product exergy

B_q = useful exergy increase of heat source or heat sink being the task of the operation

W_u = useful shaft work performed

B_f = feed exergy delivered to the system

B_{qin} = exergy decrease of feeding heat source

W_f = feeding exergy.

3.3.2 Exergetic Efficiency of Heat Exchanger NetWork

An exergy balance for the heat exchanger network is given as

$$\sum_i^n B_{i,in,hot\,stream} + \sum_i^n B_{i,in,coldstream} = \sum_i^n B_{i,out,hotstream} + \sum_i^n B_{i,out,coldstream} + I \quad (3.6)$$

$$B_{desired\ output} = \sum_i^n B_{out,coldstream} - \sum_i^n B_{in,coldstream} \quad (3.7)$$

where n is the number of heat exchangers. Because chemical exergy changes do not take place in the heat exchangers, All exergy flows in this equation can be treated as physical exergy. The desired output is the exergy increase of the crude oil stream. Therefore the exergetic efficiency of heater is

$$\eta_{HEN} = \frac{B_{desired\,output}}{B_{driving}} \quad (3.8)$$

$$= \frac{\sum_{i}^{n} B_{out,coldstream} - \sum_{i}^{n} B_{in,coldstream}}{\sum_{i}^{n} B_{out,hotstream} - \sum_{i}^{n} B_{in,hotstream}}$$

3.3.3 Exergetic Efficiency of Furnace

The exergy balance of the furnace is given by

$$B_{cold\ stream} + B_{fuel} = B_{heated\ stream} + B_{stack} + I \qquad (3.9)$$

$$B_{desired\ output} = B_{heated\ stream} - B_{coldstream}$$

the exergetic efficiency of furnace is

$$\eta_{furnace} = \frac{B_{heatedstream} - B_{coldstream}}{B_{feed} - B_{stack}} \qquad (3.10)$$

where:

I is internal exergy loss or irreversibility.

3.4 Over All Plant Analysis

The Bangchak refinery consist of two parallel plants. For this thesis only plant 2 was studied. The normal design capacity of plant 2 is 40,000 barrels per day. The plant was divided into nine units for the analysis as shown in Figure 3.1.

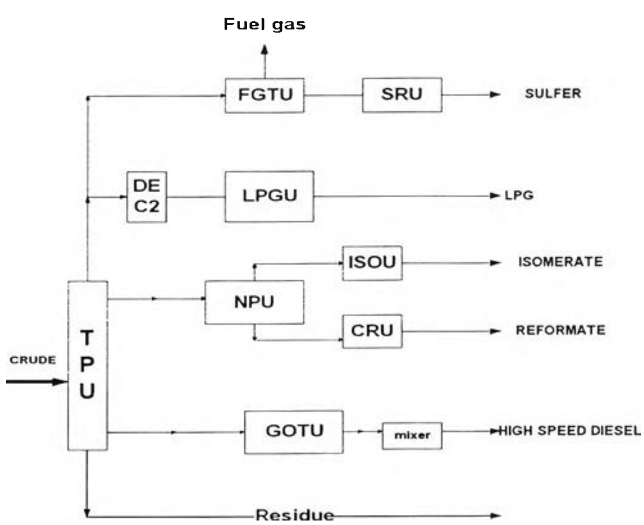

Figure 3.1 Process flow diagram of plant 2

Crude is charged in to the Topping unit (TPU) which separates it into six distillate products i.e., fuel gas, LPG, naphtha, kerosene, diesel oil, gasoil. and residue. The fuel gas from TPU and off gas from other units is sent to the Fuel Gas Treating Unit (FGTU) to remove the H_2S by scrubbing with diethyamine solution. Acid gas from the FGTU is fed to the Sulfur Recovery Unit which produces sulfur from the acid gas in the form of liquid sulfur as a product. And treated fuel gas is consumed in seven burners throughout the plant. The remainder of the gas is sent to plant 3. LPG is separated from ethane in the Deethanizer and sulfur is removed in the LPG Treating Unit (LPGU). Naphtha is fed to the Naphtha Pretreating Unit (NPU) to eliminate sulfur compounds and is separated into light naphtha and heavy naphtha. The light naphtha is reacted to form isomerate in the Isomerization Unit (ISOU) to increase the octane number by changing the paraffin naphtha to branch chain naphtha. The heavy naphtha is changed from paraffins to aromatics to increase the octane number in the Catalytic Reforming Unit (CRU). High sulfur kerosene, diesel oil, and gasoil are treated to remove sulfur compounds in the Gasoil Hydro Desulfuring unit (GOTU). The high sulfur streams are blended in the mixer to yield high-speed diesel. The residue from the bottoms of low-pressure distillation column is recovered as fuel oil for being last product. The simple process flow diagram of this plant is shown in Figure 3.2.

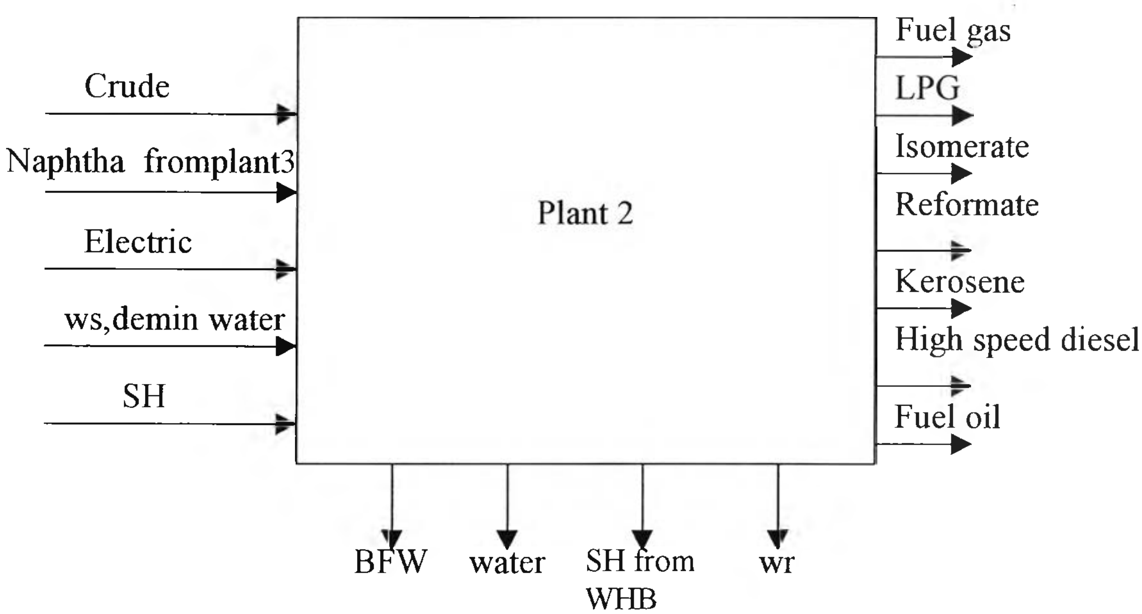

Figure 3.2 Simple process flow diagram of plant including utilities

In this study the crude oil is the mixture of three crude TP (TAPIS) =34.6%vol, Phet = 64.4%vol and LB (LABUAN) =1%vol in rate of 81 ton/hr. The API gravity of this crude and distillation curve in degree Celsius was shown in Table 3.1

Table 3.1 Distillation curve of crude oil

Method	Liquid vol.(%)	Temp(°c)	Method	Liquid vol.(%)	Temp(°c)
TBP	1 lv%	-15.1	ASTMD1160	1 lv%	-
	5 lv%	51.8		5 lv%	57.8
	10 lv%	90.3		10 lv%	95.1
	20 lv%	139.2		20 lv%	140.8
	30 lv%	187.8		30 lv%	185.8
	50 lv%	281.3		50 lv%	279.2
	70 lv%	375.9		70 lv%	374.4
	80 lv%	435		80 lv%	421.8
	90 lv%	530.2		90 lv%	501.3
	95 lv%	629.9		95 lv%	593.5
	100 lv%	794.3		100 lv%	
	API	42.5			

3.4.1 Product Composition

The composition of LPG was shown in Table 3.2

Table 3.2 Composition of lpg product

Composition	% Vol.
C_2H_6S	0.001
H_2S	0.00005
C_2H_6	0.002427
C_3H_8	0.369
IC_4H_{10}	0.2245
C_4H_{10}	0.4
C_5H_{12}	0.00364

The composition of Isomerate was shown in Table 3.3

Table 3.3 Composition of isomerate

Composition	%Vol.
Isobutane	0.001
Normalbutane	0.007
Isopentane	0.279
Normalpentane	0.092
Cyclopentane	0.015
22Dimetyhlbutane	0.156
23Dimetyhlbutane	0.053
2methylpentane	0.172
3methylpentane	0.092
Normalhexane	0.058
Methlcyclopentane	0.031
Cyclohexane	0.031
Benzene	0.000
Normalheptane	0.013

The composition of fuel gas product was shown in Table 3.4

Table 3.4 The composition of fuel gas product

Composition	%Mole
H2	0.597
H2s	0.000
CH4	0.126
C2H6	0.126
C3H8	0.061
C4H10	0.036
C5H12	0.034

4) Reformate

API gravity=48, specific gravity=0.788, heating value=46421.6kj/kg , mass fraction of C=0.86, mass fraction of H=0.14

5) Kerosene

API gravity=46.1, specific gravity=0.796, heating value=46304.12kj/kg , mass fraction of C=0.86, mass fraction of H=0.14

6) High speed diesel

API gravity=40.1, specific gravity=0.824, heating value=45909.35kj/kg , mass fraction of carbon=0.864, mass fraction of H=0.135, mass fraction of O2=0.05

7) Residue

API gravity=26.9, specific gravity=0.893, heating value=41003.2kj/kg , mass fraction of C=0.864, mass fraction of H=0.116, mass fraction of O2=0.027, mass fraction of N2=0.024, mass fraction of S=0.0131.

8) Liquid sulfur assumed to be pure liquid sulfur.