CHAPTER V
SUGGESTIONS ON THERMODYNAMIC EFFICIENCY IMPROVEMENT

The main exergy used in the plant has been supplied in the from of fuel and steam. In order to decrease the amount of these quantities the improvement of some major equipment has been studied to determine possible modifications. This chapter includes three recommendations to improve efficiency of TPU distillation column, the overall burner system, Catalytic Reforming Unit.

5.1 Application of Pinch Technique to Check the Minimum Thermodynamic Condition of the Distillation Column

The temperature-enthalpy (T-H) diagram or the tray-enthalpy diagram of a distillation column or the column grand composite curve (CGCC) is a useful representation for targeting studies and be generated from a converged simulation of a base-case column design. It was initially generated by Dhole (1992). The calculation procedure for the CGCC involves determination of the net enthalpy deficit at each stage by generating envelopes from either a condenser (top-down approach) or a reboiler (bottom-up approach). In this study the top-down approach method was used to generate CGCC. Both of methods give the similar result of the CGCC. The position and the curve of CGCC can determine the point in the column where inefficiencies arise such as the position of CGCC at feed stage far from the vertical axis will suggest a reflux modification, or a sharp enthalpy change in the profile near the feed location which indicates that feed preheating or cooling is needed.

5.1.1 Generating the CGCC

The data used in this study resulted from an already converged column simulation. Normally the simulation provides output in terms of molar flow and compositions on a stage-by-stage basis. The consideration of light and heavy keys has been specified by using the more volatile feed component as the main components of the top product as the light key and the main components of bottom product as the heavy key. The solution proceeds to the operating line equation and equilibrium line which are obtained simultaneously and incorporated in to the equilibrium compositions of the vapour and liquid streams emerging from each stage the mass equation are

$$G_{min}Y_L^{*}-L_{min}X_L^{*}=D_L \tag{5.1}$$

$$G_{min}Y_H^{*}-L_{min}X_H^{*}=D_H \tag{5.2}$$

The envelope at and after the feed stage will be

$$G_{min}Y_L^{*}-L_{min}X_L^{*}=D_L-F_L$$

$$G_{min}Y_H^{*}-L_{min}X_H^{*}=D_H-F_H$$

Where:

G_{min} = minimum vapour flow

L_{min} = minimum liquid flow

Y_L^{*} = equilibrium vapour mole fraction of light component

Y_H^{*} = equilibrium vapour mole fraction of heavy component

X_L^{*} = equilibrium liquid mole fraction of light component

X_H^{*} = equilibrium liquid mole fraction of heavy component.

And the enthalpies for the minimum vapour and liquid flows(H_{Gmin}, H_{Lmin}) are obtained from

$$H_{Gmin} = H_G^{*}(G_{min}/G^{*}) \tag{5.3}$$

$$H_{Lmin} = H_L^{*}(L_{min}/L^{*}) \tag{5.4}$$

Where:

H_G^{*} = equilibrium vapour enthalpy

H_L^{*} = equilibrium liquid enthalpy

G^* = equilibrium vapour flow

L^* = equilibrium liquid flow.

Use enthalpy balance

$$H_{def} = H_{Lmin} - H_{Gmin} + H_D \tag{5.5}$$

And the envelope at and after the feed stage is given by

$$H_{def} = H_{Lmin} - H_{Gmin} + H_D - H_{feed} \tag{5.6}$$

The CGCC can be obtained from

$$HCGCC = H_{def} + Q_{condenser} \tag{5.7}$$

the net enthalpy deficit at each stage generating envelopes from a condenser to a reboiler was presented in Figure 5.1.

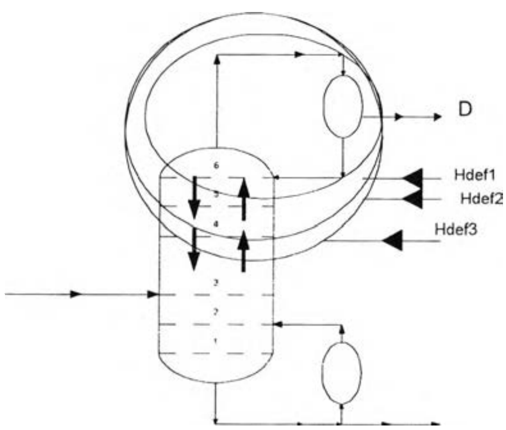

Figure 5.1 Evaluating enthalpy deficit at a stage

5.1.2 <u>CGCC of 2C102 Atmospheric Fractionator</u>

The CGCC of 2C102 generated from actual condition in process was illustrated in Figure 5.2.

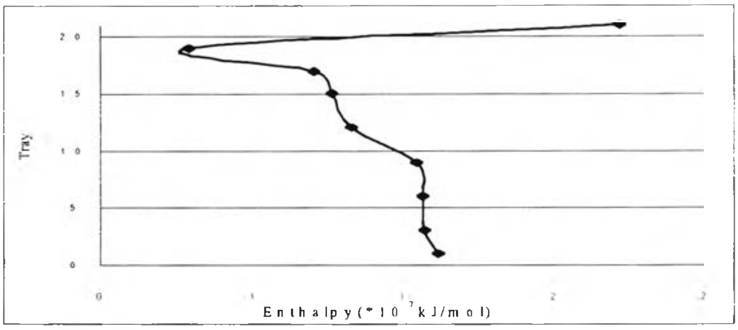

Figure 5.2 CGCC of 2C102

From the profile of the CGCC a horizontal distance between the pinch point and the vertical axis represents the scope for reduction in reflux ratio. Reduce the reflux ratio and move toward the vertical axis this reduces the condenser and stripping steam load. This shown in Figure 5.3. A reduction reflux ratio from0.35 to 0.18 gives the minimum reflux ratio that the gasoil still will be on specification. The reduced reflux ratio reduce the load on the condenser from 11.15*10^{6}kJ/hr to 11.04*10^{6}kJ/hr. This also reduces the load of stripping steam.

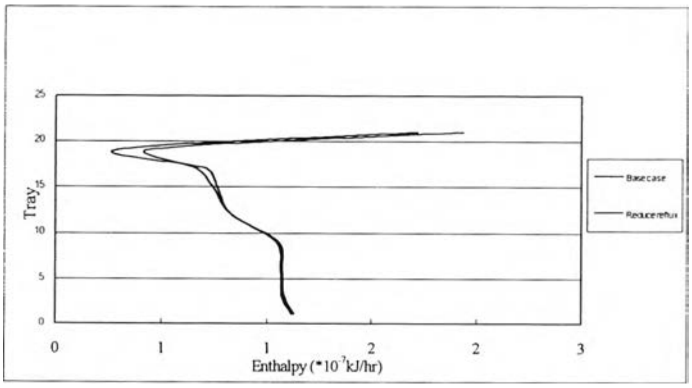

Figure 5.3 CGCC of 2C102 after reduction reflux ratio and base case

5.1.3 CGCC of 2C105 Debutanizer

The CGCC of 2C102 generated from actual condition in process was illustrated in Figure 5.4.

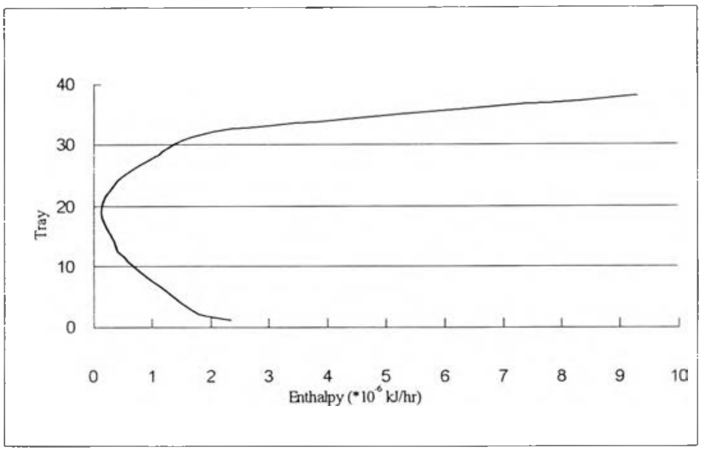

Figure 5.4 CGCC of 2C105 base case

This column has a low distance from the pinch point to the vertical axis this mean it has already has a reflux ratio close to the optimum conditions.

5.1.4 CGCC of 2C106 Deethanizer

The CGCC of 2C102 generated from actual condition in process was illustrated in Figure 5.5.

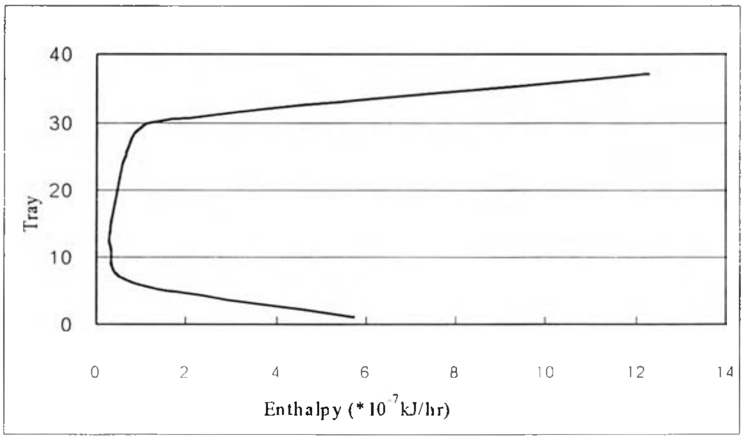

Figure 5.5 CGCC of 2C106 base case

This column also has low distance from the pinch point to the vertical axis. This means the column is operating near optimum conditions.

The CGCC can tell some point of thermodynamic imperfection and scope for improvement of the simple column but for 2C101 the CGCC cannot generate because the pump around streams do not determined in the out put of simulation program. Then it cannot determine a completely mass balance and enthalpy balance equations for each stage.

5.2 Recuperation by Preheating Combustion Reactants with Effluent Combustion Gas

Utilization of the physical exergy of the effluent combustion gas for this purpose is effective because it is not only lowers the specific physical exergy of the gasses rejected to the environment but also reduce the flow rate of these gas , due to reduction of fuel consumption.

The relative reduction of the fuel consumption in a heating furnace due to recuperation was presented in Figure 5.6 and can be determine by means of the comparison of the energy balance of the furnace chamber supplemented with a recuperator and with out a recuperator.

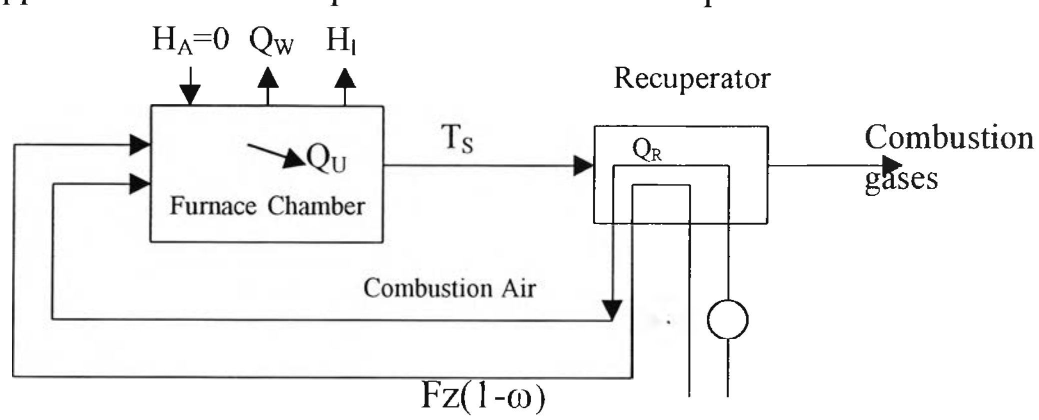

Figure 5.6 Scheme of furnace with recuperator

The energy balance for comparative furnace operating without recuperation has the form

$$F_Z C_l = Q_u + Q_w + H_l + F_z(1-\delta+\alpha)S(T_{sz}-T_0) \tag{5.8}$$

For the furnace equipped with recuperator,

$$F_z(1-\omega)(C_l+q_R) = Q_u + Q_w + H_l + F_z(1-\omega-\delta+\alpha)S(T_s-T_0) \tag{5.9}$$

where F_z = fuel consumption in the comparative furnace.

ω = fuel economy index due to recuperation

$= \frac{-\Delta F}{F_z}$

$-\Delta F$ = reduction of fuel consumption.

H_l = enthalpy of combustion gases leaking from the furnace chamber.

q_R = recuperation heat per unit of fuel

δ = relative heat capacity of the combustion gases leaking from the furnace.

α = relative heat capacity of air penetrating into the furnace chamber through leaks.

S = the mean heat capacity of combustion gas.

From Eqs 5.8 and 5.9 the fuel economy index can be calculated.

$$\omega = \frac{q_R + S(1-\sigma+\alpha)(T_{sz}-T_s)}{Cl + q_R - S(T_s - T_0)} \tag{5.10}$$

$$(T_{sz}-T_s) = (X'-1) * \frac{q_R}{S} \tag{5.11}$$

substitute 5.11 in to 5.10

$$\omega = \frac{q_R (X'-(\sigma-\alpha)(X'-1)}{C_l + q_R - S(T_s - T_0)} \tag{5.12}$$

where X'= coefficient of temperature distribution inside chamber.

The multiplier of fuel exergy economy μ_B can be defined as the ratio of the reduction of fuel exergy consumption to the exergy increase $\Delta B'$ of the pre heat of combustion of the reactants

$$\mu B = \frac{-\Delta F b_F}{\Delta B'} = \frac{\omega}{1-\omega} \frac{b_F}{\Delta b_{ph}} \tag{5.13}$$

where

Δb_{ph} = the increase of physical exergy of combustion reactants per unit of fuel

b_F = specific exergy of fuel.

This refinery already has the WHB so the stack gas temperature is not high (187°C). There fore, significant heat recovery is already inplace. The total amount of stack gas from seven furnaces is 3,200 kg mole/hr. In this study the temperature change will be from 30 to 120°c and stack temperature will reduce from 187°c to 84°c, Assume the coefficient X'=1.4, the leakage coefficient $\delta-\alpha$ =0.1 we need to find μB by $\mu B = \frac{\omega}{1-\omega}\frac{b_F}{\Delta b_{ph}}$

$$b_F = 835.86 \frac{kJ}{mol}$$

$$\Delta b_{ph} = A(t_A - t_0 - t_0 \ln\frac{t_a}{t_0}) \qquad = 0.32*(393.15-303.15-303.15\ln(\frac{393.15}{303.15}))$$

$$A = Cp*\lambda*n_A min$$

$$= 0.03*1.1*9.65 \qquad = 0.32\frac{kJ}{mol\,fuel\,°K}$$

substitute all in equation 5.12 will get ω=0.05 , Substitute in to equation 5.13 gives μB=11.12.

The delta exergy of air from 30 to 120°c is 325 kW

∴ The exergy of fuel will be reduced by 11.12*325=3623kW and the work of this fan is about 90kW. Therefore the efficiency of the furnace after installation of the recuperator will be

$$\eta = \frac{Buseful}{(Bdriving - Breduction) + Bfan} * 100$$

$$= \frac{17627.5}{((64296.2 - 3623.04) + 90)} = 29\%$$

From this number the efficiency has increase from 27.4% to 29%. It is not large because the temperature is already low due to the generation of steam by the waste heat boiler. The amount of fuel reduction is 3623 kW or 15.66kgmole/hr of fuel gas from the total is 215.75kgmole/hr. And from the amount of fuel reduction will enhance the exergetic efficiency of overall plant by reducing imported fuel oil. Therefore the new exergetic efficiency will be

$$\eta_B = \frac{1531.6+1433.1+4693.4}{26035.1-3623.} = 34.1\%$$

Although the furnace has already recovered heat from the stack gas and its temperature is low, the efficiency is nevertheless a low value. The inevitable loss from combustion and the high temperature heat transfer which occurs gives exergy loss. Therefore an avoidance of furnaces in the process is an effective way to improve the thermodynamic efficiency of the refinery.

5.3 Replace the 2F304 by a High Pressure Steam Heat Exchanger

The catalytic reforming unit uses 2F304 to heat hot oil that is passed to the convection zone of 2F301, 302, 303 and raises the temperature from 300°c to 310°c in order to be a heat source of the stabilizer reboiler of 2C301 and the debutanizer reboiler of 2C105 in TPU. This flow diagram was shown in Figure 5.7. The remainder of the heat will be use to generate saturated high pressure steam from the BFW in 2E309 because the temperature of hot oil is equal with the SH. Therefore, it can used as a heat source instead of the hot oil. In additional the bubble point and dew point of the reformate in the operating pressure are 216, 234°C. Therefore, the temperature of SH is high enough to be heat source in the reboiler.

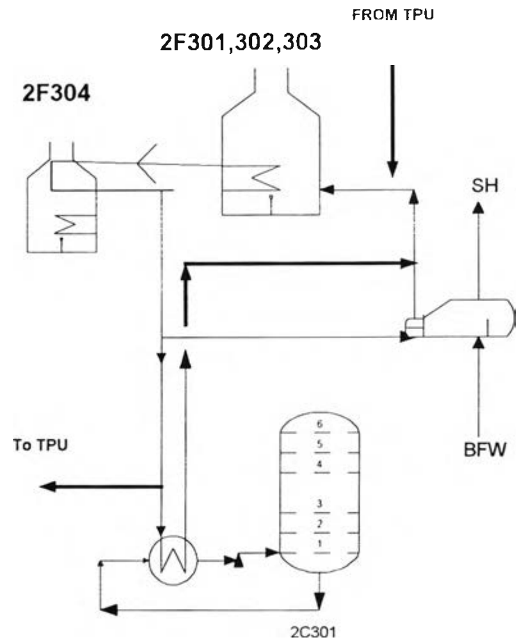

Figure 5.7 Scheme of 2F304 in CRU

The new flow diagram of the CRU after using SH instead of hot oil the Bcredit will not have ΔB hotoil that is exported to the TPU but it will have the $\Delta B_{SH\text{-}BFW}$ that derives the BFW through the convection zone of 2F301, 302, 303. For Bof driving the amount of fuel gas used in 2F304 about 16 kgmole/hr can be replace by ΔB of SH and CPH(high pressure condensate). The modification scheme diagram and the result obtained from the calculation were illustrated in Figure 5.8 and Table 5.1 respectively.

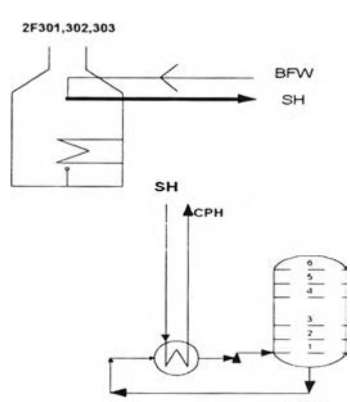

Figure 5.8 New scheme of 2F304 in CRU

Table 5.1 The exergy of every stream for new scheme CRU

Input		Exergy (kW)	**Output**		Exergy (kW)
Feed			Products		
Heavy naphtha	B_{phy}	51.5	Reformate	B_{phy}	7.3
	B_{che}	329066.2		B_{che}	281009.2
		48057.0	H_{21}	B_{phy}	0.8
				B_{che}	42.7
			H_{22}	B_{phy}	81.8
				B_{che}	4910.8
			LPG	B_{phy}	61.6
				B_{che}	38164.1
			Top2c302	B_{phy}	23.8
				B_{che}	5186.6
			Top2d302	B_{phy}	0.2
				B_{che}	18.0
Credit					
BFW	B_{tot}	161.7	SH	B_{tot}	2445.0
Cooling water in			**Cooling water out**		
E302	B_{tot}	1191.0	E302	B_{tot}	1192.4
E303	B_{tot}	1016.4	E303	B_{tot}	1017.5
E306	B_{tot}	1111.6	E306	B_{tot}	1112.9
E307	B_{tot}	327.1	E307	B_{tot}	327.5
Electricity		147.7			
2F301	B_{phy}	9.6	stack	B_{phy}	205.1
	B_{che}	3556.0		B_{che}	257.0
2F302	B_{phy}	23.4	stack	B_{phy}	335.2
	B_{che}	5804.9		B_{che}	419.6
2F303	B_{phy}	9.3	stack	B_{phy}	158.9
	B_{che}	2752.3		B_{che}	199.0
AIR in	B_{phy}	9.0			
Steam					
SH to reboiler	B_{tot}	1445.4		B_{tot}	844.6
SH(in) 2k301	B_{tot}	2919.4	SL(out) 2k301	B_{tot}	2094.9

Efficiency of new scheme for CRU is

$$\eta_B = \frac{\Delta B_{product-feed} + \Delta B_{SH-BFW} + B_{mixing}}{\Delta B_{wr-ws} + \Delta B_{fuel\,gas\,3\,burners-stack} + \Delta B_{SH-CPH\,in\,reboiler} + \Delta B_{SH-SL\,in\,turbine\,compressor} + B_{elec}}$$

=23.8%

In comparison with 15.9% of the base scheme it was indicated that a furnace yield a high exergy loss for which it should be avoided if another heating system can be substituted.