

# The Integrated Simulation and Optimization for Absorption-stabilization System and Gas Processing Unit

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This paper presents the integrated simulation and optimization for absorption stabilization system of fluid catalytic cracking unit (FCCU) and gas processing unit (GPU). The optimization objective function, optimization variables and constraints are proposed. Through the optimization of the two units the deethanizer of GPU is eliminated and the propylene recovery rate for the GPU is enhanced from the original 94.8% to approximately 99%. This optimization was successfully implemented in China Petroleum & chemical Corporation Guangzhou branch in 2004 and no extra equipment revamping is required. The simulation results show that the net propylene yield increase is 1756 tons per year and the net total annual profit enhancement is 855,440USD for a 1,200,000t FCCU and a 120,000t GPU.

**Keywords:** integrated simulation, optimization, FCCU, gas processing.

## 1. Introduction

This paper describes the integrated simulation and optimization for the FCCU and the GPU. FCCU is to turn the heavy petroleum fractions into light fractions with the products of liquefied petroleum gas (LPG), stabilized gasoline and diesel oil. GPU processes the above LPG to obtain high purity propylene. People are often used to the individual unit design. Therefore, it is rare to consider other relevant units for the best global economic profits when one unit is undergoing design. From literatures the majority papers describe the individual unit improvements (Hall and Northup, 1995, p63; McDonald, 1992, p79) and the integrated optimization among different units are hardly found.

The FCCU and GPU all have a light component gas emissions. The former is from the secondary absorber overhead with the components of  $N_2$ ,  $H_2$ ,  $O_2$ ,  $C_1$ ,  $C_2$ ,  $C_3$ ,  $C_4^+$  etc.; The latter is from the deethanizer overhead with the components mainly  $C_2$ ,  $C_3$ . For both emissions the  $C_2$  with lighter components should be removed and the  $C_3$  with heavier components should be recovered. However, both emissions lead to both  $C_3^+$  losses.

Usually the GPU consists of three columns that are depropanizer, deethanizer and  $C_3^-$  splitter. In order to obtain high purity propylene deethanizer must be equipped to remove small amount ethane. A lot of propylene is exhausted from the deethanizer overhead with the ethane removal. The propylene content in the deethanizer overhead is usually in the range of 60~80%. Therefore, the propylene loss is quite severe in this

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column, which possesses about 70~85% of the total propylene losses. In general, for traditional GPU the maximum  $C_3^=$  recovery rate is around 95% and is hard to further enhance owing to the existence of deethanizer. Table1 shows the  $C_3^=$  losses for 120,000t/yr gas processing unit. The deethanizer overhead is usually sent to the fuel gas network. The propylene price is much higher than that of fuel by 5 times.

If the deethanizer can be eliminated, the propylene recovery rate would reach to about 99%, which means the net annual propylene yield can be increased by 1700 tons for a 120,000 tons unit. Unfortunately, at present all the gas processing units equipped with deethanizers. The only way to eliminate deethanizer is to control the C2 concentration in the feedstock to a new specification which is low enough so that the high purity propylene can be produced without the deethanizer.

Table 1  $C_3^=$  losses for 120,000t/yr gas processing unit

column	Depropanizer	Deethanizer	$C_3^=$ splitter
Process specifications	C4 in distillate & C3in bottoms $\leq$ 0.1%	C2 in bottoms $\leq$ 0.01%	$C_3^=$ in distillate $\geq$ 99.6%, $C_3^0$ in bottoms $\geq$ 97%
$C_3^=$ loss (kg/hr)	5	228	47
Percentage of $C_3^=$ loss(%)	1.79	81.43	16.78
$C_3^=$ flowrate in feedstock (kg/hr)		5146	
$C_3^=$ recovery rates (%)		94.56	

From the view point of integrated design and optimization, those light component emissions should be combined together instead of individual exhausting as they were. The right place is from the secondary absorber in FCCU. At the same time the specification for the LPG C2 concentration should be modified to match the new requirement of GPU.

## 2. Model, optimization variables and objective function

### 2.1 Model and optimization variables

First, the process simulation model for absorption-stabilization system and GPU should be established based on the existing units. Simulator Aspen Plus is used to perform this work. As there are no recycle streams between these two units, the simulation model can be either a united one or two individual models for FCCU and GPU respectively.

The process flowsheets and the unit real production data are essential based on which the real unit simulation can be performed. The simulation results have to match the existing production data. Otherwise, the next optimization is very hard to conduct.

Second, the most important step is to perform the integrated optimization for the both units. So far as optimization is concerned, the optimization variables must be determined first. How to specify optimization variables from vast process parameters is also critical. However, till now not many articles address this issue. The usual adopted method is still based on experiences. In this work the method proposed by literature (Lu et al., 1998, p113) is adopted and hence the optimization variables for FCCU are determined. For GPU the optimization is relatively simple. A suitable process conditions with no deethanizer should be found by simulation.

## 2.2 Objective function

Objective function is usually the maximum economic profit. The profit can be calculated from the following:

$$Profit = sales - costs \quad (1)$$

For the existing units optimization the costs for the feedstock, labor, maintenance, insurance and taxes are invariant. Therefore, the equation (1) can be simplified as follows:

$$P = \sum Si * Wi - \sum C \quad (2)$$

Where:

P-simplified profit; Si-product prices; Wi-product flowrates; C-operation cost

The products for the absorption-stabilization system consist of the stabilized gasoline, LPG and the off-gas. The products for GPU are the propylene, C3<sup>o</sup>, C4 fraction as LPG product and off-gas. The  $\sum C$  is the total costs of the cooling water, heat medium and power.

## 3. New C2 specifications of LPG for the integrated optimization

In order to eliminate the deethanizer, the feedstock LPG must reach a new specification. Usually the C2 concentration is in the range of 0.5~2% for existing FCCU. The process simulations are made for different C2 content in LPG and the results listed in table 2. From the results it can be seen that the new specification for C2 concentration in LPG should be controlled within the range of 0.01~0.1%. If the C2 concentration reaches to 0.15%, the target to obtain 99.6% propylene is almost impossible, because the C2 concentration in the propylene product approaching to 0.4%. Another problem is the reflux ratio is too high, so that the condenser can not have the flexibility to bear this heat duty.

Table 2 The C2 impact on the C3<sup>o</sup> purity in C3<sup>o</sup> splitter distillate

C2 concentration In LPG (mol%)	0.01	0.02	0.04	0.06	0.08	0.1	0.15
Reflux ratio	17.36	17.63	18.25	19.03	20.07	21.36	36.91
Condenser duty (Mkcal/hr)	-7.02	-7.13	-7.37	-7.67	-8.07	-8.57	-14.53
Reboiler duty (Mkcal/hr)	6.97	7.07	7.31	7.62	8.01	8.51	14.47
Distillate composition (mol%)							
Ethane	0.03	0.05	0.10	0.15	0.20	0.25	0.37
Propylene	99.6	99.6	99.6	99.6	99.6	99.6	99.6
propane	0.37	0.35	0.30	0.25	0.20	0.15	0.03

## 4. Simulation and Optimization for absorption-stabilization system

Although this work is integrated simulation and optimization for FCCU and GPU, the main calculations are concentrated in the FCCU. In order to make the C2 content in LPG lower than 0.1%, the stripper bottom temperature has to be enhanced. But it will lead the C3 content in the off-gas increase rapidly. Therefore, the C3 recovery rate and the energy consumption will be influenced. However, it is our goal that in the same time of controlling the C2 concentration in LPG to a new level, these two parameters are still maintained or even get better.

As we have mentioned that the optimization variable select is critical. The following variables are chosen as the optimization variables:

- The flowrate of supplementary absorbent
- The feed temperature of stripper

- The C4 content of the stabilizer bottoms

The equation (2) is used as the optimization objective function. The prices are as follows: LPG-\$337.35/t; gasoline-\$313.25/t; propylene(99.6%)-\$722.9; off-gas-\$96.38/t; water-\$0.042/t; power-0.078/kwh; steam-\$12.65/t; these prices are all converted to US dollars from Chinese local prices.

The constraints for the absorption-stabilization system optimization are the followings:

- The C2 concentration in LPG  $\leq 0.05\%$ (mol%)
- The C3 concentration in off-gas  $\leq 1.5\%$ (mol%)
- Stripper feed temperature  $\leq 42^\circ\text{C}$
- The C4 concentration of stabilizer bottoms  $\geq 3.5\%$ (mol%)
- The supplementary absorbent flowrate  $\leq 25\text{t/h}$

Simulations for both cases, the base case and optimization case, are performed and the key results are given in table 3

Table 3 Key process parameters for the two cases

cases	Base case	Optimization case
C2 concentration in LPG (mol%)	0.62	0.05
C3 concentration in off-gas (mol%)	1.5	0.9
Stripper feed temperature( $^\circ\text{C}$ )	74	41
Stripper top temperature( $^\circ\text{C}$ )	71.7	50.4
Stripper bottom temperature( $^\circ\text{C}$ )	114	117
C4 concentration in stabilizer bottoms (mol%)	5	3.5
stabilizer condenser temperature( $^\circ\text{C}$ )	44.6	46.8
stabilizer bottom temperature ( $^\circ\text{C}$ )	180	184
supplementary absorbent flowrate(kg/h)	17,000	20,000

The main process parameter changes for the optimization case are as follows:

- The stripper feed temperature is decreased by  $33^\circ\text{C}$ ;
- The supplementary absorbent flowrate is increased by 3,000kg/hr;
- The stripper bottom temperature is increased by  $3^\circ\text{C}$ ;
- The stabilizer bottom temperature is increased by  $4^\circ\text{C}$ ;

Through the above measurements the C2 concentration in LPG is lowed to 0.05% and the unit profit get enhanced. Especially, for most existing absorption-stabilization systems there is a stripper feed pre-heater to increase the feed temperature, say to  $74^\circ\text{C}$ , so that the C2 components keep better deabsorbing. However, this temperature enhancement will lead to the higher C3 losses in off-gas. Therefore, it is not an appropriate measurement from the integrated design view of point. The pre-heater is deleted in the optimization case, which is a breakthrough to the traditional prevailing processes.

## 5. Profit comparisons

### 5.1 The gas processing unit

The process simulation and optimization are performed for the GPU base case (with deethanizer) and optimization case (without deethanizer). As the optimization case eliminates the deethanizer the propylene recovery rate is dramatically increased to 99.03% (mol %). See table 4.

Table 4 The comparison of the  $C_3$ = recovery rate for the two cases of GPU

Items	$C_3$ in feedstock (kg/hr)	$C_3$ yield (kg/hr)	$C_3$ recovery rate (wt %)
Base case	5146	4866	94.56
Opt. case	5130	5080	99.03

The profit comparison is given in table 5 for the two cases. It can be seen that the profit increase for the optimization case is 72.93USD/hr, corresponding to the annual net profit 583,400USD.

Table 5 The profits comparison for the two cases of GPU (USD/hr.)

	Sales income(S)	Utility cost(U)	Profit(S-U)
Base case	6944.10	291.05	6653.02
Opt. case	7026.26	300.32	6725.95
	Opt-Base	Opt.-Base	Total
profits increase for opt. case	82.16	-9.27	72.93

### 5.2 The absorption-stabilization system

For the absorption-stabilization system although the  $C_2$  concentration requirement is more severe, the profit for the optimization case still get enhanced. See table 6.

Table 6 The profits comparison for the two cases of FCCU (USD/hr.)

	Sale's income(S)	Utility cost(U)	Profit(S-U)
Base case	25995	190.3	25804.7
Opt. case	26027	188.3	25838.7
	Opt-Base	Base-Opt	Total
Net profits increase for opt. case	32	2	34

### 5.3 The total profit enhancement

The net profit enhancements for FCCU and GPU are 34 and 72.93 USD/hr respectively. If the annual operating hours are 8,000, the net total profit enhancements for the integrated optimization are 855,440USD per year.

## 6. Implementation

This integrated optimization was successfully implemented in China Petroleum & chemical Corporation Guangzhou branch in March, 2004. During the 17 days test running the propylene product kept the purity above 99.6 % (mol %) with no difficulties. The propylene recovery rate reached 98.8%. The FCCU and GPU were all in good and stable operation status without any problems occurred.

## 7. Conclusions

This paper presents the integrated simulation and optimization for the two units FCCU and GPU. The study also proposes the optimization objective function, optimization variables and constrains. The industrial implementation proved that the deethanizer can

be eliminated and the propylene recovery rate for the GPU can be enhanced from the original 94.56% to approximately 99%. The simulation results show that the net total annual profit enhancements are 855,440USD.

Through the computer patent and article searching the integrated process suggested in this paper is complete new and no similar processes are found.

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