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Cost Estimation and Optimization of the Topping Unit Products at the Steady State Condition

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Abstract

Optimization pays an important role in the growing world of competition in the industrial countries. It is the aim of this research to optimize the topping unit of a Gas Refinery in Iran (i.e., Khangiran Gas Refinery) using Hysys software. To obtain this objective, a nonlinear SQP (Sequential Quadratic Program) model has been adopted in this study for the optimization purposes. The objective function was chosen in a way that it would maximize the annual income by considering the utility and maintenance cost. To impose some limits on the primary and secondary variables for the optimization purposes, the operating variables must not exceed an allowable limit and the unit have got to operate in the steady state condition. The primary variables that are adopted in this study for the optimization are the two feed streams to the unit. Given that the composition of the two feed differs and the product must be kept constant, we could obtain the optimal values. The result demonstrates that we have got to impose a constraint function on the secondary parameters so as to minimize the reboiler and condenser heating loads. In this research we maximized the rate of naphtha production with regard to the solvent and diesel fuel and minimized it with respect to kerosene, while maintaining the same overall capacity. The findings of this study revealed that through the sale of the unit products we would be able to make a net profit in the margin of about $ 7863626 annually, and raise the annual income by as much as 1.4 percent through the optimization scheme.

Keywords: Optimization, SQP, Kerosene, Topping unit, Hysys software.

1. Introduction

Optimization of chemical processes is of great importance from both economical and practical point of view. Justifications for the high energy cost, decline in the world raw materials, environmental problems and cost have led the companies to underline on such processes. Designing the topping unit is of complex nature which makes the modelling more complicated (Naphtali, 1971; Tomich, 1970; Russel, 1983 and Kumar *et al.*, 2001). In order to come up with a proper model and to perform the optimization, it was essential to carry out the simulation and then perform the exact sizing of the whole unit. To obtain this objective, simulation was first carried out in 2005 by Saghatoleslami (Dadmohamdi, 2005). To carry out the simulation and design the unit, the "Modified Hysim Inside Out" method was adopted in this work. Table 1 exhibits the simulation results of this study and the original design specifications of the unit. There exist a small discrepancy between the simulation result of this work and original design specifications of the unit. This could be caused by the lack of some information about the original design specifications. To assess the results, a comparative study has also been made between the simulation result of this work and current actual specifications of the unit (Table 2). It revealed that there is a good agreement between the numerical findings of this study and the current actual values from the unit. It was also demonstrated that the Hysys software is a powerful and accurate design tool for the simulation of such a process.

Furthermore, topping unit is unique in its kind for converting condensate into precious light hydrocarbons products such as solvents, naphtha, kerosene and diesel. The feed of this unit were supplied from the gas treating units (GTU), gas gathering centre and stabilizer. The classification adopted for these feeds are based upon their volatility. As a result, the light and heavy feeds were named S-400 and S-500, respectively. The unit includes a distillation unit of two different diameters, thirty one trays, a condenser, two side strippers and a reboiler. A schematic flow diagram of the unit is shown in Figure 1. In order to maximize the income and keep the costs to the minimum, the objective function should be a function of the above parameters. To obtain this objective, it was essential to manipulate the variables and allow some of the variables to be adjusted in way such as to achieve the necessary limits. Furthermore, to enhance the results and to accomplish the required limits for a particular variable, it was essential to apply some constraints on the objective function.

2. Theory

Hysys contains a multi-variable steady-state optimizer. Once the flowsheet has been built and a converged solution has been obtained, the optimizer could be utilized to find the operating conditions which minimize (or maximize) an objective function. The following terminology is used in describing the optimizer:

- Primary variables which are imported from the flowsheet whose values are manipulated in order to minimize (or maximize) the objective function
- Objective function is the function which should be minimized or maximized
- Constraint functions are defined in three ways. Inequality and equality constraint functions which may be defined in the optimizer spreadsheet. The other technique is the box, mixed and sequential quadratic programming (SQP) methods which could be employed for the constrained minimization with inequality constraints. Finally, the Fletcher-Reeves and quasi-Newton methods which are available for the unconstrained optimization problems

In this work, for the optimization purposes an objective function was adopted in such a way that it would maximize the profit and keep the costs to the minimum (Cutler, 1983). SQP is considered by many to be the most efficient method for minimization with general linear and non-linear constraints, provided a reasonable initial point is used and the number of primary variables is small. The objective function in the Hysys software is defined as:

$$\Phi = \Psi_1 - \Psi_2 - \Psi_3 - \Psi_4 - \Psi_5 \tag{1}$$

In the case where is required to minimize the objective function, it could be written as:

$$\Phi = -\left(\Psi_1 + \Psi_2 + \Psi_3 + \Psi_4 + \Psi_5 \right) \tag{2}$$

where:

Ψ_1 : profits obtained by selling the products (i.e., solvent, naphtha, kerosene and diesel)

Ψ_2 : cost of raw materials (i.e., gaseous condensate)

Ψ_3 : utility cost (i.e., cooling water and electricity)

Ψ_4 : unit fuel cost

Ψ_5 : unit maintenance cost

It was also possible to estimate other expenditures such as labour and skilled workers through this method.

3. Products revenue, cost of raw materials, utility charges, fuel and maintenance cost

From the gaseous condensate, products such as solvent, naphtha, kerosene and diesel fuels could be extracted. If these products are made in accordance with the standards, a profit of about 2498 \$/hr could be achieved by selling them (Table 3). The cost of raw materials, cooling water and electricity charges for the unit and the cost of fuel consumption are also exhibited in Tables 4, 5 and 6, respectively.

The schedule maintenance causes the unit work properly during the operation and it consists about 2 percent of the total fixed capital cost. The fixed capital cost on itself includes the price of the equipment, insulation cost and other direct and indirect charges. However, in chemical industries, about 25 percent of the total fixed capital cost goes towards purchasing the machinery. However, as the purchasing information of the unit was not available, we were only able to add up the price of a single unit and to come up with the total fixed capital cost.

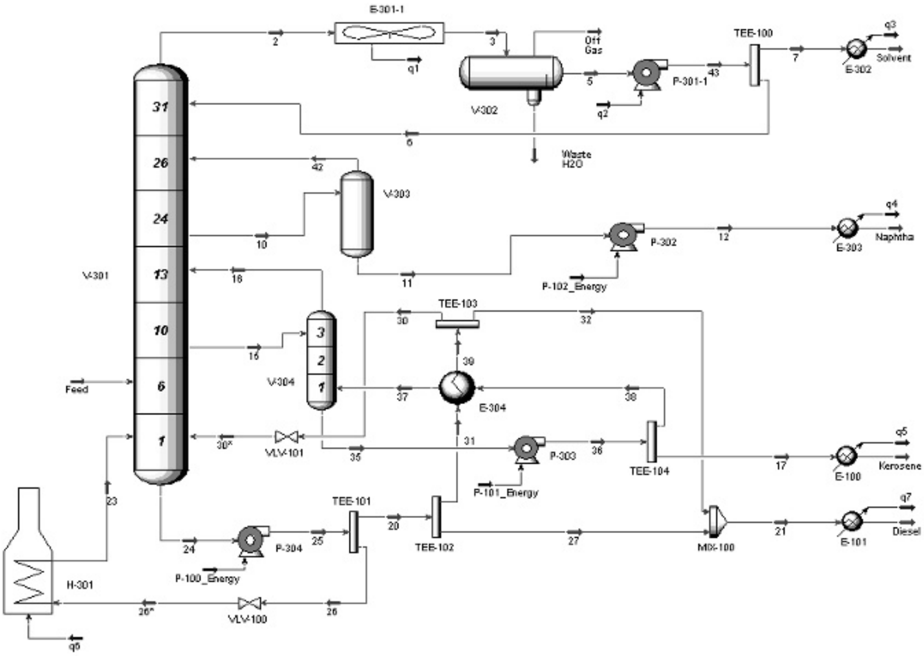

Figure 1: Schematic flow diagram of the gaseous condensate distillation unit

Table 1: Comparative studies between the Hysys simulation results of Saghatoleslami (Dadmohamdi, 2005) and original design specifications of the unit

Column parameters and operating variables	Original design specification	Numerical results (Dadmohamdi, 2005)
Solvent product flow rate (kg/hr)	142.71	145
Naphtha product flow rate (kg/hr)	3329.20	3330
White naphtha product flow rate (kg/hr)	1241.92	1240
Diesel product flow rate (kg/hr)	1009.5	1008
Temperature on the 31st tray (^{0}C)	67.5	65.3
Temperature on the 24th tray (^{0}C)	132.5	131
Temperature on the 10th tray (^{0}C)	208.5	207
Bottom product flow rate (kg/hr)	35355	35400

Table 2: Comparative studies between the Hysys simulation results of Saghatoleslami (Dadmohamdi, 2005) and current actual values of the unit

Column parameters and operating variables	Actual values of the unit	Numerical results (Dadmohamdi, 2005)
Solvent product flow rate (kg/hr)	142.71	143
Naphtha product flow rate (kg/hr)	3329.20	3330
White naphtha product flow rate (kg/hr)	1241.92	1200
Diesel product flow rate (kg/hr)	1009.5	1010
Temperature on the 31st tray (^{0}C)	67.5	67.5
Temperature on the 24th tray (^{0}C)	132.52	133
Temperature on the 10th tray (^{0}C)	208.6	209
Reflux ratio (kg/hr)	47.70	47.70

Table 3: Estimation of income from selling the products

Products	Flow rate (ton/hr)	Unit price ($/ton)	Sales profit ($/hr)
Solvent	0.127	360	45.72
Naphtha	1.890	360	680.40
Kerosene	3.360	470	1579.20
Diesel	0.448	430	192.64
			2498

Table 4: Costs of raw materials

Condensate	Cost at refinery ($/kg)	Consumption of the unit (kg/hr)	Total cost ($/hr)
S-400 (light feed)	0.291	2332.132	678.65
S-500 (heavy feed)	0.2109	3498.198	737.77
		5830.33	1416.42

Table 5: Utility Charges

Utility	Consumption	Unit price	Costs ($/hr)
Cold water	91670.48 (kg/hr)	0.00422 ($/kg)	3.874
Electricity	372159.58 (Btu/hr)	0.00318 ($/Btu)	4.906
			8.780

Table 6: Fuel Charges

Fuel	Consumption (m^3/hr)	Unit price ($/$m^3$)	Charges ($/hr)
Gas	495	0.1147	56.814

4. Total unit cost

The unit that was studied in this work consists of four water coolers, one reboiler, one distillation tower, twenty pumps, fifteen tanks, one air cooler, one heat exchanger, four vessels (i.e., V-301, V-302, V-303 and V-305) and one packed side stripper (i.e., V-304). The unit prices were taken from the updated Cost Index Chemical Engineering (CE), as shown in Table 7. From this table we could compute the total fixed capital cost which is shown below:

Fixed capital cost = (2292608.5)/ (0.25) = \$9170434

Maintenance cost = (0.02) (9170434) = \$183408.68

Annual profits for 330 operating days could be computed manually as follows:

$\Psi_1 : \$19783843.2$ $\Psi_2 : \$11218046.4$ $\Psi_3 : \$69537.6$

$\Psi_4 : \$449966.8$ $\Psi_5 : \$183408.7$ $\Phi : \$7863626.5/\text{year}$

The result revealed that the annual profits are quite significant in comparison to the direct sales of the condensate.

5. Optimization

To conduct the optimization scheme, we initially gave all cost and income values as an input to the software. To obtain the maximum profit, some primary variable which plays an important role in achieving the product, were also introduced to the software. Then, we imposed some constraints on these variables (Basak *et al.*, 2002). To obtain the optimum conditions for both feeds (i.e., the condensate stream rates of S-400 and S-500), some limits were imposed for these variations:

$$0 \langle \text{ flow (stream S}-400) \langle 3280 \text{ kg/hr} \quad ; \quad 0 \langle \text{ flow(stream S}-500) \langle 3599 \text{ kg/hr}$$

These flow limitations were achieved by considering the relationships between the unit and the fluctuations of the maximum annual production capacity. To accomplish the optimum conditions, except the primary variables, we could impose some constraint function on the secondary variables as well. These limitations imposed on the secondary variables are exhibited below:

$\text{Flow rate of naphtha} \rangle \text{ Flow rate of solvent}$

$\text{Flow rate of naphtha} \langle \text{ Flow rate of kerosene}$

$\text{Condenser heat flow} \langle 715.6 \text{ kW}$

$\text{Flow rate of naphtha} \rangle \text{ Flow rate of diesel}$

$\text{Furnace heat flow} \langle 1423 \text{ kW}$

$\text{Total flow rate} \leq 5830.33 \text{ kg/hr}$

The effective parameters and the method employed in this work for obtaining the maximum profit are shown in Table 8. Comparative studies have also been performed between the optimum primary variables which are shown in Table 9. These values were achieved by solving the objective function and the initial values.

Table 7: Distillation unit costs

Units	Numbers	Costs ($)
H-301-1	1	125500
V-301-1	1	74609.75
V-302-1	1	3976
V-303-1	1	6106
V-304-1	1	16352.45
V-305-1	1	6876
E-301-1	1	4359.55
E-302-1	1	27.81
E-303-1	1	708.99
E-304-1	1	195.955
E-305-1	1	483.32
E-306-1	1	483.32
P-301A/B	2	12424.5
P-302A/B	2	10165.5
P-303A/B	2	10040
P-304A/B	2	15060
P-305A/B	2	18323
P-310A/B/C	3	18448.5
P-311A/B	2	16942
P-312A/B	2	16315
P-313A/B	2	15060
P-314A/B	2	15061
T-301A/B	2	753000
T-302A/B	2	125500
T-303A/B	2	376500
T304A/B	2	527100
T-305A/B	2	122990
		$2292608.5

Table 8: Effective parameters in the optimization method

Data model	Original
Scheme	SQP
Maximum function evaluations	300

Table 9: Comparative studies between the optimum primary variables obtained from this work and the initial values

Operating variables	Initial values	Optimum values
Tower temperature (^{0}C)	68.9	70.2
24th tray temperature (^{0}C)	134	135
10th tray temperature (^{0}C)	209	209
Solvent flow rate (kg/hr)	127	135
Naphtha flow rate (kg/hr)	1890	1850
Kerosene flow rate (kg/hr)	3360	3420
Diesel flow rate (kg/hr)	448	420
S-400 flow rate (kg/hr)	2332	2231.4
S-500 flow rate (kg/hr)	3498	3599
Annual profit	7863626.6	7974838.3

6. Conclusion

In this research, the topping unit of the Khangiran Gas Refinery were optimized using Hysys software. The result revealed that from the sale of the condensate products such as solvent, naphtha, kerosene and diesel, a net profit in the margin of about \$7863626 could be obtained annually. Furthermore, we could also raise the annual income by as much as 1.4 percent through this optimization scheme. Therefore, it could be stated that the Hysys software is a powerful and accurate design tool for the simulation of such a process.

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