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SIMULATION STUDY AND OPTIMIZATION OF THE OPERATING VARIABLES AFFECTING THE PERFORMANCE OF AN EXISTING CONDENSATE STABILIZATION UNIT

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Abstract

Nowadays, gas processing for condensate, NGLs (Natural Gas Liquids), and LPG (Liquefied Petroleum Gas) recovery has gained great interest due to the increase of the market demands as well as the higher prices of these products. However, many of the present condensate, NGL and LPG recovery units in operation don't give the desired revenue. The need to achieve the highest efficient performance, maximum productivity rate, stable operation, and reducing the operating cost of the ABU-SANNAN Condensate Stabilization Unit (General Petroleum Company - EGYPT) by optimization of the process operating conditions has led to this work. Based on production data and operation conditions of the existing Condensate Stabilization Unit and by close monitoring of butanes content in stabilizer feed stream and stabilizer bottom product (stabilized condensate), it is clear that the operation of Condensate Stabilization Unit favors enrichment of butanes in the bottom product at the expense of pentanes plus (poor fractionation). The existing condensate stabilization unit is simulated using the Aspen HYSYS simulator V8.8, which is based on PENG-ROBINSON equation of state for calculations. Model results are verified by testing against the actual process operating conditions. The most important process variables and constraints that directly affect the production and performance ratio of the stabilization unit are discussed firstly, to illustrate the relationship between process operating conditions and the change could be appearing on the objective functions; subsequently the optimal process operating conditions are developed to achieve a stable column operation. Economic analysis has been carried out to determine the performance and profitability of the plant after optimization. The most effective process operating variables investigated in this work are outlet temperature of process gas from the Mechanical Refrigeration Unit, stabilizer feed drum pressure, stabilizer column pressure, stabilizer feed temperature, stabilizer bottom temperature, stabilizer feed tray location, and stabilizer reflux ratio. The results show that, after development of the optimum process operating conditions, stabilizer bottom product purity increased by 0.80%, condensate productivity increased by 26.25% (33 BBLs/D), while total consumed power reduced by 4.16% (2.56 MMBTU/D).
The economic analysis shows that there is excess revenue in the gross profit by about $ 1,594,050 / year as a result of optimization. The efforts done in this work are helpful and can be applied for plants in operation as well as the plants under design for increasing their profits.

Keywords: *Optimization; Condensate stabilization; Simulation.*

1. Introduction

Distillation is the primary method of separation in the process industry and is the most common form of separation technique used to separate a mixture of components that have different boiling points, by boiling the more volatile components out of the mixture preferentially. The degree of separation of a multi component system depends on properties of the feed mixture, operating conditions, and other process imposed restrictions. The main purpose of this process is to reduce the vapor pressure of the condensate liquids to prevent the production of vapor phase upon flashing the liquid to atmospheric storage tanks. On the other hand, the scope of this process is to separate very light hydrocarbon gases, methane and ethane, in particular, from the heavier hydrocarbon components (C_{3+}) [1-3].

Process simulation has become an essential tool for operators and engineering firms in the oil & gas industry. Simulators can better support process design, debottlenecking, and optimization when used to their full potential. Aspen HYSYS is the market-leading process modeling and simulation solution with a proven track record of providing substantial economic benefits throughout the process engineering lifecycle. It brings the power of process simulation and optimization to the engineering desktop and delivers a unique combination of modeling technology and ease of use [4-5].

Change in the operating condition of the column changes the composition or purity of the desired component(s) and the amount of heat that may be recovered. In order to reduce the operating costs of a plant, much effort is put to find the optimal design condition of the process through optimization studies. Optimization has many applications in chemical, mineral processing, oil and gas, petroleum, pharmaceuticals, and related industries. Not surprisingly, it has attracted the interest and attention of many chemical engineers for several decades [6-7].

The target of condensate stabilization unit optimization process is to improve the products quality, minimizing energy consumption, and to achieve stable operation. Since the stabilization section represents the equipment's that have the highest consumed power and can contribute to more than 50% of plant operating cost [8].

2. ABU-SANNAN condensate stabilization unit process description

The ABU-SANNAN condensate recovery plant located about 300 km West of Cairo in the Western Desert of Egypt. The plant is designed to process 85 MMSCFD of high pressure gas and recover 3000 BBLs of condensate per day. The overall scheme for the Exiting Plant can be broken to four sections consisting of the gas receiving, liquid extraction, liquid stabilization and gas compression, the block diagram for the main unit operations in the existing gas plant is shown in Figure 1.

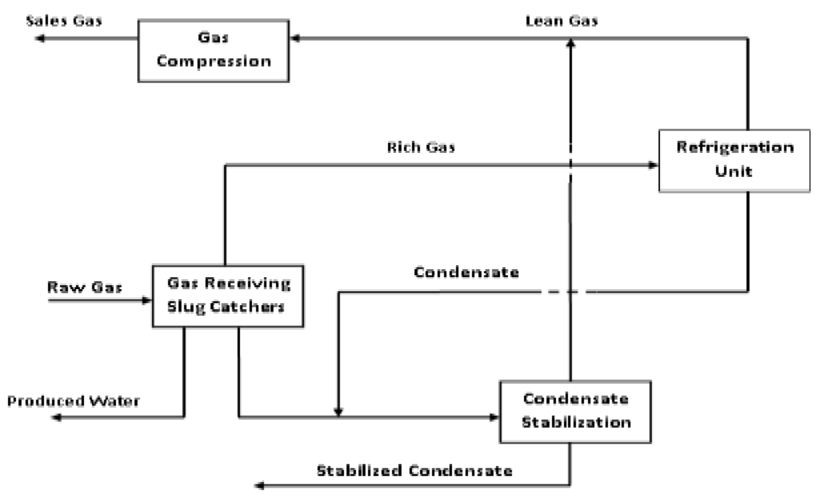
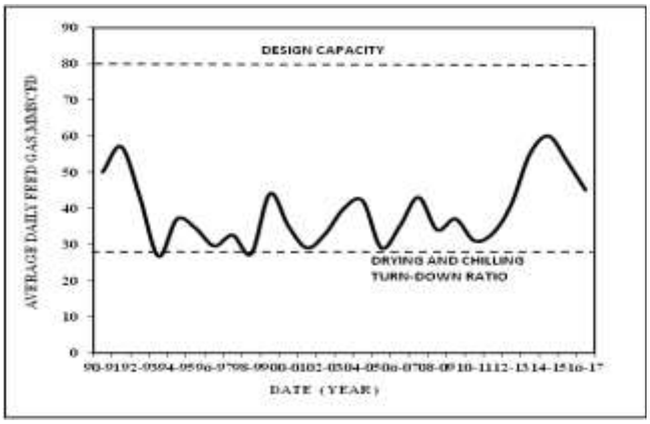


Figure 1. Block diagram for the existing condensate recovery plant

Condensate stabilization section consists of Stabilizer feed drum (30-V-7) where condensate from high pressure flash drum (V-5) passes through a pressure control valve to (V-7) that results in reducing pressure in (V-7) which lead to flashing amount of gas. This will reduce the heat requirement in stabilization process. Stabilizer inlet feed heat exchanger (30-E-5) used to increase stabilizer inlet feed temperature by exchanging with outlet condensate product from stabilizer bottom. Condensate stabilizer column (30-C-1) the stabilizer function is to remove butane and lighter components from the condensate to produce a stabilized condensate suitable for storage with a maximum RVP of 12 psia at 100°F, it has 30 valve trays. Condensate product air cooler (30-A-3) condensate bottom product from stabilizer column is passed through air cooler that reduces temperature to about 35°C before storage in floating roof tanks.

Design turn-down ratios are: overall plant is 33 % or (28.05 MMSCFD), and Condensate Stabilization Section is 37 % or (1110 BBLs/Day). The actual operation is above turn-down ratio for the entire plant. However, stabilizer operation has been below turn-down ratio, and therefore, its operation needs careful examination. Figures (2 and 3) illustrate average daily feed gas and condensate production rate from 1990 to 2017 respectively [9].



Figures 2. Feed gas history from 16 /10/1990 to 1/5 /2017

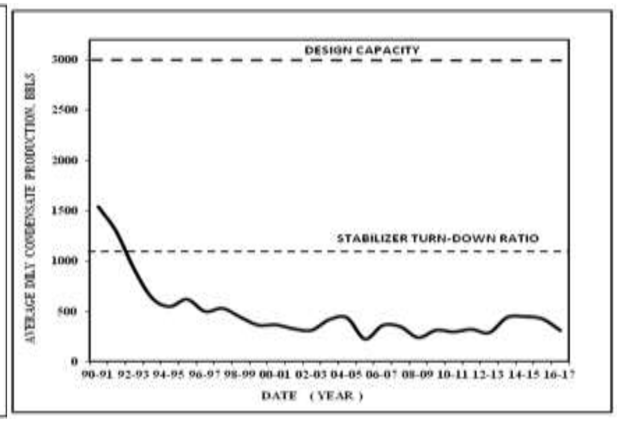


Figure 3. Condensate production history from 16 /10/1990 to 1/5 /2017

3. Research methodology

The plan of this study is constructed in the following steps:

Data extraction where stabilizer feed (un-stabilized condensate), stabilizer overhead product, and stabilizer bottom product (stabilized condensate) samples are taken from the plant to be analyzed in the General Petroleum Company laboratory. The actual process operating conditions of the existing unit are obtained from daily plant operating conditions log sheets, see Table 1.

Table 1. Actual process operating conditions

Process variable	Unit	Value
Process gas temperature after chilling	°C	-5
Stabilizer feed drum pressure	kg/cm²	16.5
Stabilizer column pressure	kg/cm²	12.6
Stabilizer feed temperature	°C	60
Feed tray	—	19
Reflux ratio	%	0.5

Constructing a steady state model for the existing condensate stabilization section by using ASPEN HYSYS V-8.8, while the model validation is conducted by testing against a period of five months for which production and operation conditions data are available. Statistical analyses of the real operating plant data and simulation results are conducted to check for any deviation between them.

Optimization of the process operating conditions where the sensitivity analysis for the operating conditions is performed firstly to illustrate the relationship between operating conditions and the change could be appearing on the objective variables, subsequently obtain the optimum operating conditions. One parameter is subjected to change at a time, while other parameters are kept constant for the simulation model to not deviate from the actual operating situation [8, 10].

4. Results and discussion

The flow sheet of the condensate stabilization section in the HYSYS property template is shown in Figure 4, while Table 2 compares the compositional analysis for the stabilizer OVHD product stream obtained from laboratory analysis and simulation results. Similarly, Table 3 compares the compositional analysis for the stabilizer bottom product stream.

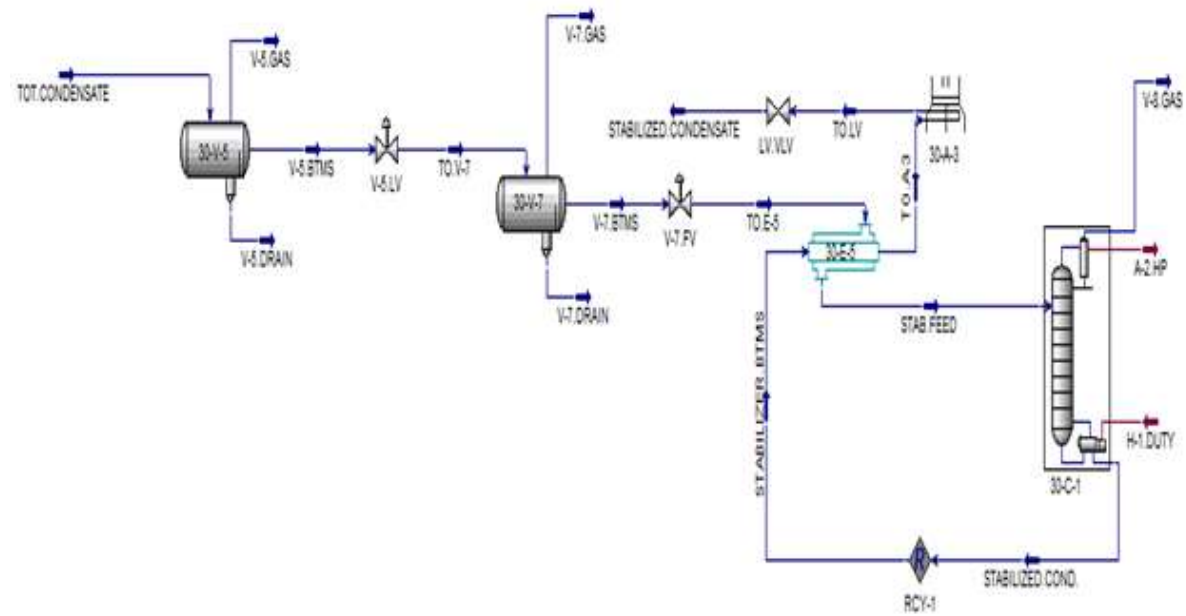


Figure 4. The flow sheet of condensate stabilization section

Table 2. Comparison between simulation results and laboratory analysis for the stabilizer overhead product stream (mole fraction)

Component	Laboratory data	Simulation results
Methane	0.0692	0.0808
Ethane	0.1511	0.1480
Propane	0.3075	0.3169
i-Butane	0.1529	0.1435
n-Butane	0.2522	0.2477
Pentane plus	0.0623	0.0578
CO_2	0.0048	0.0053

Table 3. Comparison between simulation results and laboratory analysis for the stabilizer bottom product stream (mole fraction)

Component	Laboratory data	Simulation results
i-Butane	0.0045	0.0027
n-Butane	0.0340	0.0331
Pentane plus	0.9615	0.9642

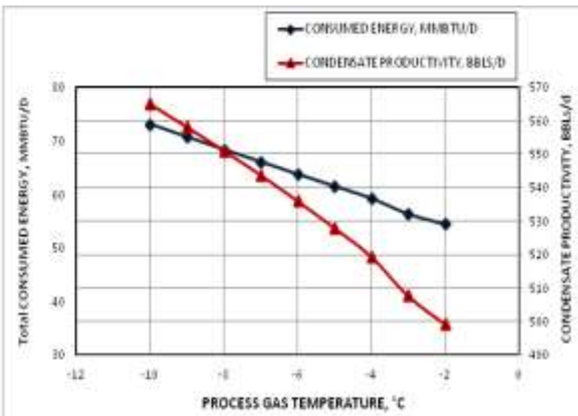
From the previous comparison, it is clear that the model produces a valid agreement with the production data.

4.1. Sensitivity analysis for condensate stabilization section operating conditions

The most important process variables and constraints that directly affect the production and performance of the plant are discussed in this section, as in the following.

4.1.1. Effect of outlet temperature of process gas from the refrigeration unit

Figure 5 illustrates the relation between outlet temperature of process gas from propane chiller, the corresponding total consumed energy, which includes energy consumed equipments (re-boiler duty, condenser power, and compressor energy), and condensate productivity rate. It is clear that as the temperature of process gas decrease in the outlet of refrigeration cycle, condensate productivity rate increase as a result of heavier hydrocarbon condensation, and totally consumed energy increased considerably as a result of increasing propane chiller cooling duty. Figure 6 illustrates the relation between outlet temperature of process gas from propane chiller, specific energy consumption, how much energy should be consumed to produce one barrel of condensate, and pentanes plus mole fraction, as the indicator of separation performance for the stabilizer column. It is clear that as the temperature of process gas decreased, the separation performance increased, while the specific energy consumption decreased.



Figures 5. Effect of process gas temperature on process objective functions

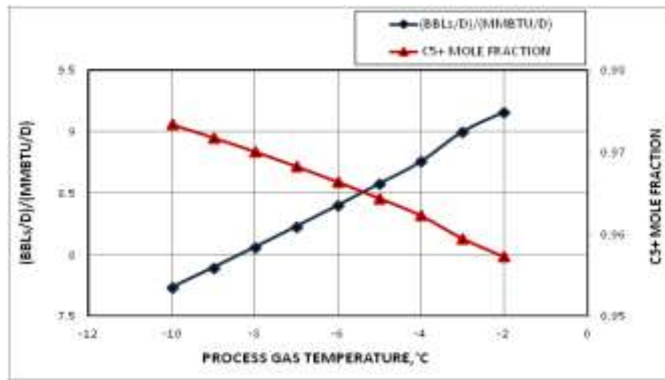
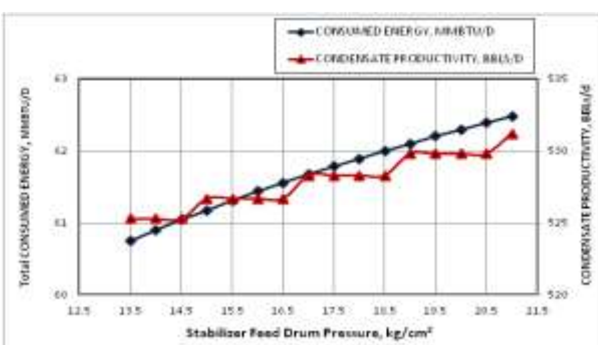


Figure 6. Effect of process gas temperature on separation performance

4.1.2. Effect of stabilizer feed drum (V-7) pressure

The pressure of stabilizer feed drum is controlled by a pressure controller on the vapor line. Figure 7 illustrates the relation between stabilizer feed drum pressure and objective functions. It is clear that stabilizer feed drum pressure has low effect on total consumed energy and condensate productivity rate, while Figure 8 illustrates the relation between stabilizer feed drum pressure, specific energy consumption, and pentanes plus mole fraction.



Figures 7. Effect of V-7 pressure on process objective functions

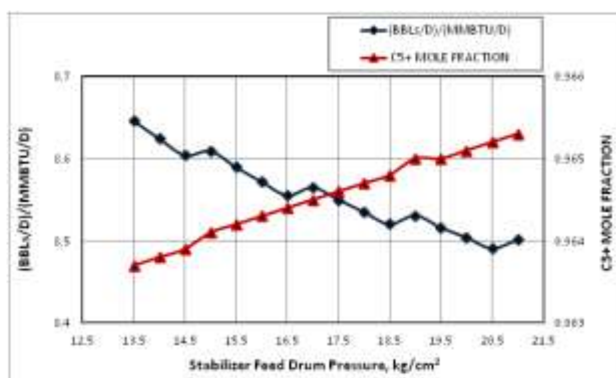
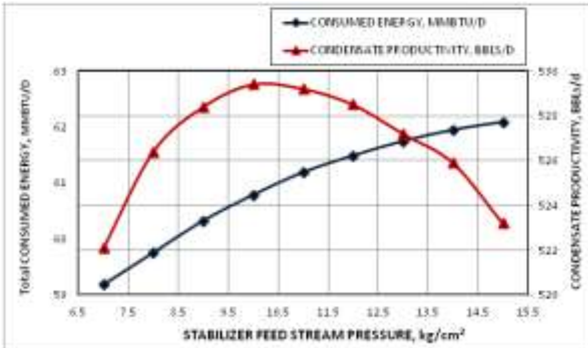


Figure 8. Effect of V-7 pressure on separation performance

4.1.3. Effect of stabilizer feed stream pressure

The column operating pressure is directly controlled by the column overhead vapors. Figure 9 illustrates the relation between stabilizer feed stream pressure and objective functions. It is clear that stabilizer feed pressure is direct affects total consumed energy and condensate productivity rate, while Figure 10 illustrates the relation between stabilizer feed pressure, specific energy consumption, and pentanes plus mole fraction.



Figures 9. Effect of Stabilizer feed pressure on the objective functions

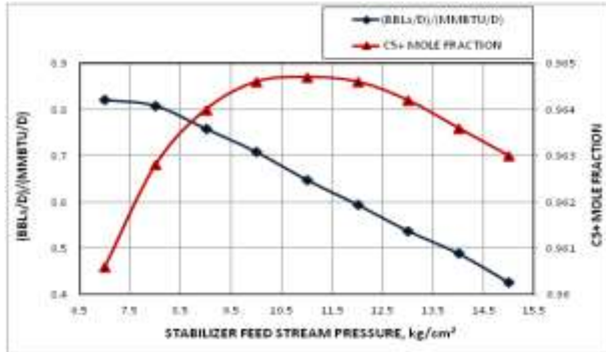


Figure 10. Effect of stabilizer feed stream pressure on separation performance

4.1.4. Effect of stabilizer feed stream temperature

The inlet feed stream to stabilizer is heat transferred with the bottom product from stabilizer, and its temperature is maintained by means of a temperature controller operating a valve on the by-pass line around the stabilizer heat exchanger (30-E-5). The effect of inlet stream temperature on the objective functions plotted in Figure 11. It is clear that as the stabilizer feed temperature increased, total consumed energy and condensate productivity rate decreased considerably, while Figure 12 illustrates the relation between stabilizer feed stream temperature, specific energy consumption, and pentanes plus mole fraction.

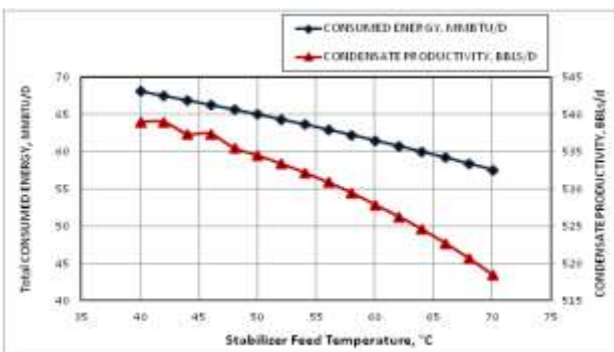


Figure 11. Effect of Stabilizer feed temperature on the objective functions

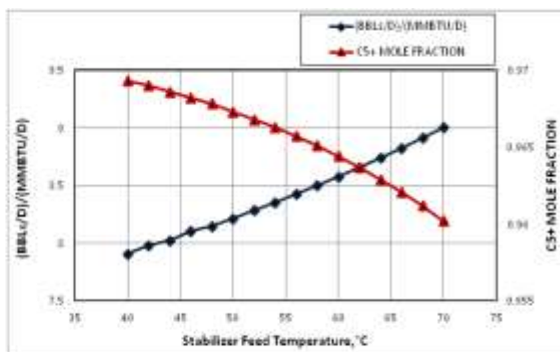


Figure 12. Effect of stabilizer feed temperature on separation performance

4.1.5. Effect of stabilizer bottom temperature

The stabilizer column has 30 valve trays, and the stripping efficiency is determined by the bottom temperature. Figure 13 illustrates the relation between stabilizer bottom temperature and the objective functions. Figure 14 illustrates the relation between stabilizer bottom temperature, specific energy consumption, condensate RVP and pentanes plus mole fraction.

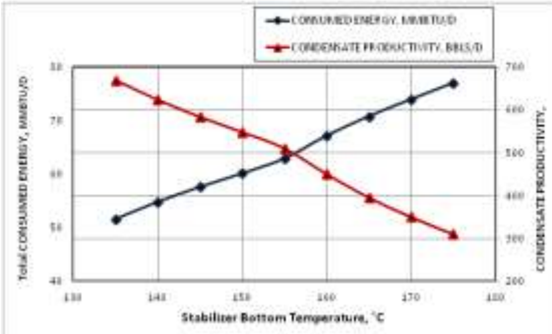


Figure 13. Effect of Stabilizer bottom temperature on the objective functions

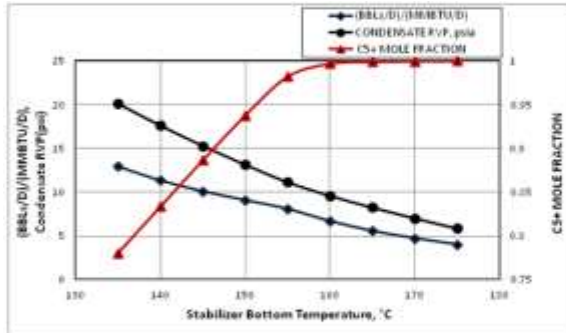


Figure 14. Effect of stabilizer bottom temperature on separation performance

4.1.6. Effect of stabilizer feed tray location

Since the stabilizer feed composition may vary, provision has been made to bring the feed at any of three tray locations (tray 13, 15, or 19); only one must be opened to ensure proper performance of column. Figure 15 illustrates the relation between stabilizer feed tray location and the corresponding total consumed power. Figure 16 illustrates the relation between stabilizer feed tray location and productivity rate. Figure 17 illustrates the relation between stabilizer feed tray location and pentanes plus mole fraction.

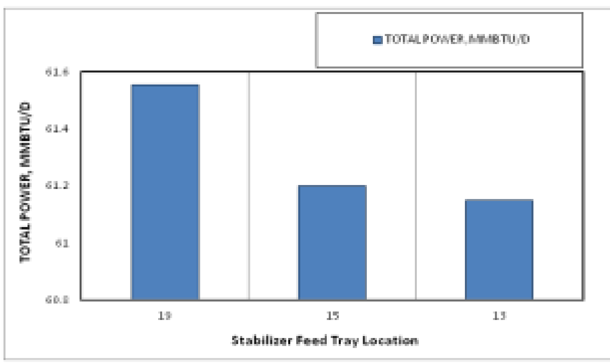


Figure 15. Effect of stabilizer feed tray location on total consumed power

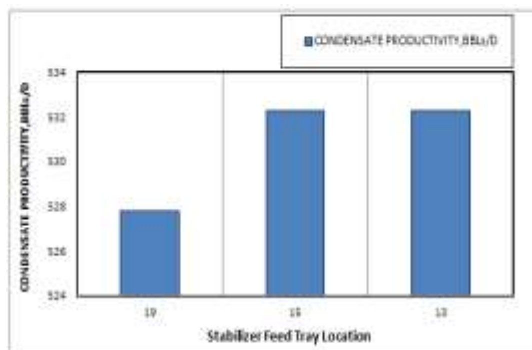


Figure 16. Effect of stabilizer feed tray location on condensate productivity

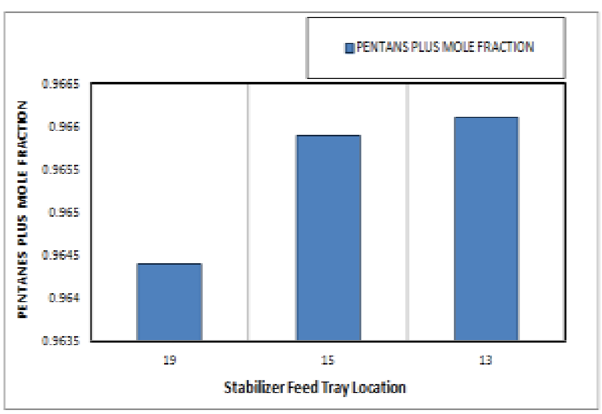


Figure 17. Effect of stabilizer feed tray location on separation performance

4.1.7. Effect of stabilizer reflux ratio

The reflux rate is set to achieve a good separation between the C4 and C5 components. The flow is regulated with flow controller. The effect of reflux ratio on total consumed power and condensate productivity rate plotted in Figure 18, while Figure 19 illustrates the relation between stabilizer reflux ratio, specific energy consumption, and pentanes plus mole fraction.

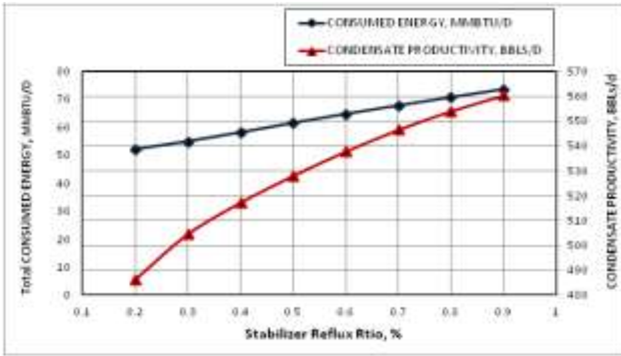


Figure 18. Effect of reflux ratio on the objective functions

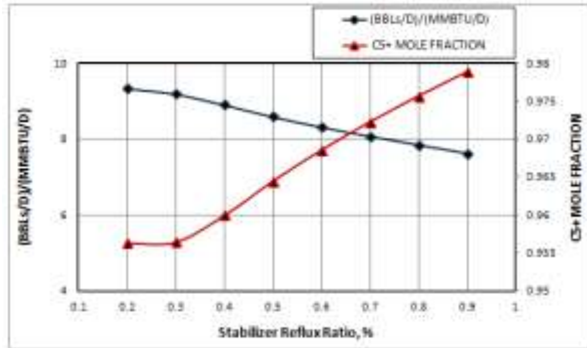


Figure 19. Effect of stabilizer reflux ratio on separation performance

4.2. Sensitivity analysis of the refrigeration unit operating conditions

The aim of this section is to minimizing propane compressor horse power and minimizing the refrigerant mass flow rate.

4.2.1. Impact of inter stage pressure on compression power

Figure 20 illustrates the relation between inter stage pressure and compression power. It is clear that as the inter stage pressure increase, first stage compression power increase, and second stage compression power decrease. The minimum total compression power at inter stage pressure equal to 8 kg/cm².

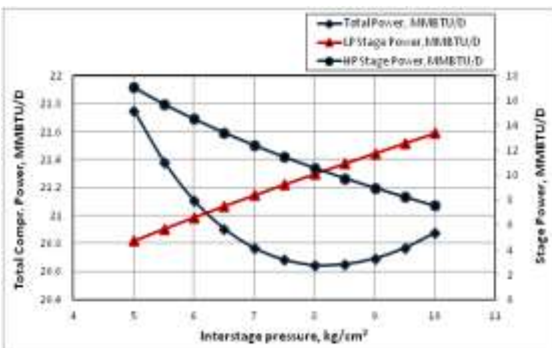


Figure 20. Impact of inter stage pressure on compression power

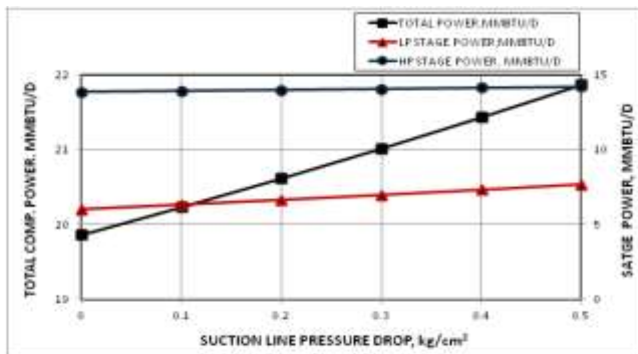


Figure 21. Impact of suction pressure drop on compression power

4.2.2. Impact of compressor suction pressure drop on compression power

Figure 21 illustrates the relation between compressor suction pressure drop and compression power. It is clear that as the compressor suction pressure drop increase, first stage compression power increase, second stage compression power slightly increase and the total compression power increase considerably.

4.2.3. Impact of propane inlet temperature to chiller on compression power

Figure 22 illustrates the relation between propane inlet temperature to chiller and compression power. It is clear that as the propane inlet temperature to chiller decrease, first stage compression power increase, second stage compression power slightly increase and the total compression power increase considerably.

4.3. Development of the optimal operating conditions

Based on the results from the sensitivity analysis of stabilization section process operating conditions, it is clear that the operation of stabilizer column involves a trade-off between energy consumption and product quality, so the aim of this section is to define the optimal process conditions that will lead to maximizing the product purity and productivity with minimal change in energy consumption using HYSYS optimizer.

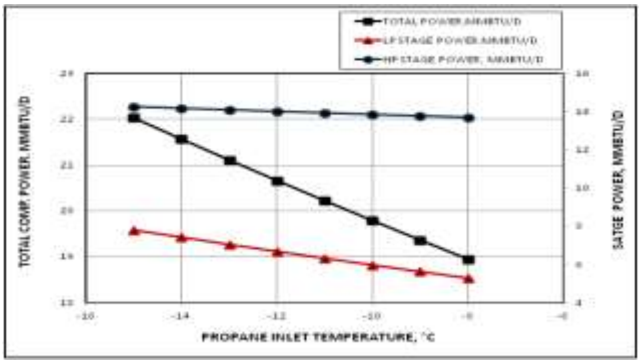


Figure 22. Impact of propane inlet temperature on compression power

After completion of HYSYS optimizer sheet, the optimization model was run, and the model results were obtained. Compared results of base and optimized case for stabilization section are introduced in Table 4, while compared results of base and optimized case for refrigeration unit are introduced in Table 5.

Table 4. Comparison between base case and optimized case of condensate stabilization section

		Base case	Optimized case
Objective function	C5+ mole fraction	0.964	0.972
Function constrain	Condensate production, BBL/D	528	561
	RVP, psia	12.00	12.00
	Consumed power, MMBTU/D	61.56	62.21
Function primary variables	Chiller outlet temperature, °C	-5	-6
	V-7 pressure, kg/cm²	16.5	13.6
	Stabilizer feed pressure, kg/cm²	12.7	9.5
	Stabilizer feed temperature, °C	60	57
	Stabilizer bottom temperature, °C	153	141
	Reflux ratio, %	0.5	0.61
	Stabilizer feed tray	19	13
Specific energy consumption, (BBLs/D)/(MMBTU/D)		8.57	9.02

Table 5. Comparison between base case and optimized case of refrigeration unit

		Base case	Optimized case
Objective functions	Compression horse power, kW	247.8	208.7
	Refrigerant mass flow rate, kg/hr	9195	9137
Function constrain	Chiller cooling duty, MMBTU/D	48.28	48.28
Function primary variables	Inter stage pressure, kg/cm²	6.2	8.0
	Suction pressure drop, psia	4.27	1.00
	Propane inlet temperature, °C	-12.8	-8.0

5. Feasibility study and economic evaluation

The total operating cost is obtained by using Aspen Capital Cost Estimator V 8.8. For the original plant = $ 3,684,010 / year, while for the optimized plant = $ 3,599,080/ year. Table 6 and 7 illustrates daily products sales revenue for the original and optimized plant.

Table 6. Daily products sales revenue for the original plant

Products	Quantity	Unit	Selling price, $/unit	Total sales price, $
Sales gas	67,585	MMBTU	2.65	179,100
Stabilized condensate	526	BBLs	80	42,080
	Total sales price, $			2,97

The total annual sales revenue for the original plant is $ 79,624,800.

Table 7. Daily products sales revenue for the optimized plant

Products	Quantity	Unit	Selling price, $/unit	Total sales price, $
Sales gas	180,492	MMBTU	2.65	179,100
Stabilized condensate	44,880	BBLs	80	42,080
	Total sales price, $			225,372

So, the total annual sales revenue for the optimized plant is $ 81,133,920.
Gross profit = Total sales revenues – Total product cost
For the original plant = $ 79,624,800 – $ 3,684,010 = $ 75,940,790.
For the optimized plant = $ 81,133,920 – $ 3,599,080 = $ 77,534,840.

6. Conclusion

This work has provided a framework for analyzing and improving the performance of an existing condensate recovery plant, where condensate recovery plants in operation require continuous innovation and adaptation in process technologies and suitable selection of operating conditions in order to increase their revenue.

The outcome of this work shows that the process operating variables played an important role in improving condensate productivity, separation performance, and power consumption of the condensate stabilization column. This work is restricted by the fact that all the process variables were not simultaneously modified for the model not deviated from the real process operating situation.

From this research, it can be concluded that:

- It is seen the increase in objective function (pentanes plus mole fraction) by 0.8 % of original case with increasing in condensate production by 6.25% (33 BBLs/D), while the consumed energy increased by 1.05 % (0.65 MMBTU/D), as a result of the optimization of condensate stabilization section operating conditions.
- After the optimization of the mechanical refrigeration unit, total power consumption of the optimized plant is decreased from 62.21 to 59 MMBTU/D (4.2% power saving of original plant power).
- From the economic evaluation, and comparison of gross profit from original and optimized plants, it is clear that there is excess revenue in the gross profit by about $ 1,594,050/year as a result of optimization.

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