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Modification of a Natural Gas Sweetening Process for Reducing Energy Consumption

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Abstract

Amine gas sweetening is the most used process in oil and gas industry to remove acid gases like H_2S and CO_2 from natural gas. This study highlights one of the main characteristics of amine gas sweetening process which has high energy requirements. In order to reduce the energy consumption of this process, a modification considered the process configuration has been suggested. This modification was investigated by Aspen HYSYS version 11 as a simulation tool. The case study used to show the benefits of the introduced modification in a giant natural gas sweeting plant in Egypt. The obtained results show that circulation of the side semi-lean amine stream from the regenerator to the absorption column leads to a reduction of the energy consumption of the considered plant by about 18% and a reduction of the reboiler duty by 12%. This effect has a great importance in case of limited steam production. Furthermore, the introduced modification decreases the utilities cost by about 11%. From these results, it is clear that the proposed modification is of high importance in decreasing the energy consumption which in turn increases the profits of the investigated plant.

Keywords: *Natural gas sweetening; MDEA, Energy consumption; Aspen HYSYS; Structure modification; retrofitting.*

1. Introduction

Natural gas is considered the major source of energy in the world nowadays. It is also a source of hydrocarbons for petrochemical feedstocks and a major source of elemental sulfur, an important industrial chemical. Natural gas has many remarkable merits that made it more desirable than petroleum and coal according to environmental aspects. Natural gas production produces carbon dioxide at a rate of 0.5 to 0.7 times of that produced from coal and petroleum. In addition, burning natural gas forms nitrogen oxides which are about 20% of those produced from oil or coal burning. As it is known, carbon dioxide (CO_2) and the nitrogen oxides (NOx) are greenhouse gases which causes global warming. Moreover, particulate formulation is greatly more in oil and coal than in gas. Particulates lead to air quality degradation and major health problems [1].

About 37 % of global electricity is generated from coal burning due to its availability and low cost (World Coal Association, 2023). However, the global interest towards natural gas has increased significantly in the last ten years due to its lower CO_2 emissions compared to other types of fossil fuels like coal [2].

According to IEA energy outlook report 2008, around 40% of natural gas reserves contain H_2S and CO_2 [3]. They are the most dangerous contaminants in natural gas as they can create a lot of problems such as plugging, erosion, corrosion, health damage and environmental hazards [4]. Hence, it's very important to remove these impurities from natural gas to meet health, environmental and specifications requirements. The concentration of H_2S and CO_2 in the natural gas stream must be kept below 4 ppm and 2% mol respectively [5].

Natural gas sweetening (i.e., the removal of H_2S and CO_2 acidic gases from natural gas) is one of the necessary processes in the hydrocarbon industry. There are many separation techniques of acid gas sweetening such as, amines (chemical), Selexol (physical), Sulfinol (mixed physical and chemical) and membranes/molecular sieves adsorption, etc. Amine gas sweetening is the most used process in oil and gas industry due to its higher removal efficiency and low maintenance requirements. In addition, it's more flexible to operate [3]. Mono-ethanolamine (MEA), di-ethanolamine (DEA) and methyl di-ethanolamine (MDEA) are most often used as an absorbing media for cleaning of natural gas. It is found that MDEA is the best absorbent due to its great selectivity towards H_2S, low corrosivity and high loading capacity [6]. Also, MDEA process is more energy efficient and economically applicable over other amine-based sweetening processes [7].

Nowadays, most of acid gas removal units depends on the absorption/regeneration process using methyl di-ethanolamine (MDEA) as a solvent with concentration of 40 to 50 % in water [8]. Amine sweetening process contains basically high-pressure absorber, regenerator, heat exchanger, air cooler and reboiler. Despite its high efficiency of acid gas removal, energy consumption related to amine process is considered very high that may affect the whole process by adding essential operating costs [9].

Energy requirements around amine sweetening process has been always one of the main objectives to be studied. Most of the energy is consumed by the regenerator reboiler [10]. Optimization of energy consumption around amine process becomes an important object for most operating companies to reduce their spending. A considerable reduction of energy consumption of natural gas sweetening process and process optimization can be achieved by process modification and there are many ways to reach this goal such as replacing amine type, modifying column internals or modifying configuration of the process [11].

Since the beginning of using amine sweetening process, many structures have been suggested to modify and optimize the process. In 1934, Sholed proposed the idea of taking a part of the amine in the regenerator as a side stream and feeding it back to the absorber. Such configuration is called split-flow configuration [12]. Split flow amine process is also discussed qualitatively by Polasek in 1982 confirming that split flow configuration can reduce the required rate of stripping steam [13]. Al-Lagtah et al. and Cousins *et al.* used aspen HYSYS to show simulation of split-flow configuration [11,14]. In addition, other process configurations are studied before such as entering amine from different stages in absorber column and an intermediate flash unit before the regenerator [12], but these modifications were already applied on the considered plant taken as the case study in the present work. The plant already made some modifications aiming to increase the amount of gas flowrate that can be handled such as changing the type of regenerator trays.

The aim of this research work is to study the split-flow modification technique on the plant under consideration as a way of minimizing energy consumption, and to evaluate its effect on the whole process. The main advantage of split-flow structure is the reduction in reboiler duty as there is a part of rich amine that will not totally be regenerated.

2. The case study

The acid gas removal unit of the investigated plant contain three functional sections. The first section which called the absorption section contains the equipment required to absorb H2S and to preheat feed gas with the produced sweet gas. The second section called the regeneration section contains the equipment required to regenerate the rich amine and to produce lean amine recycled back to absorber. The third section called the recycling section contains the equipment required to recycle the produced lean amine from the regenerator back to the absorber.

The typical sweeting process described in Figure 1 is discussed in the following subsection.

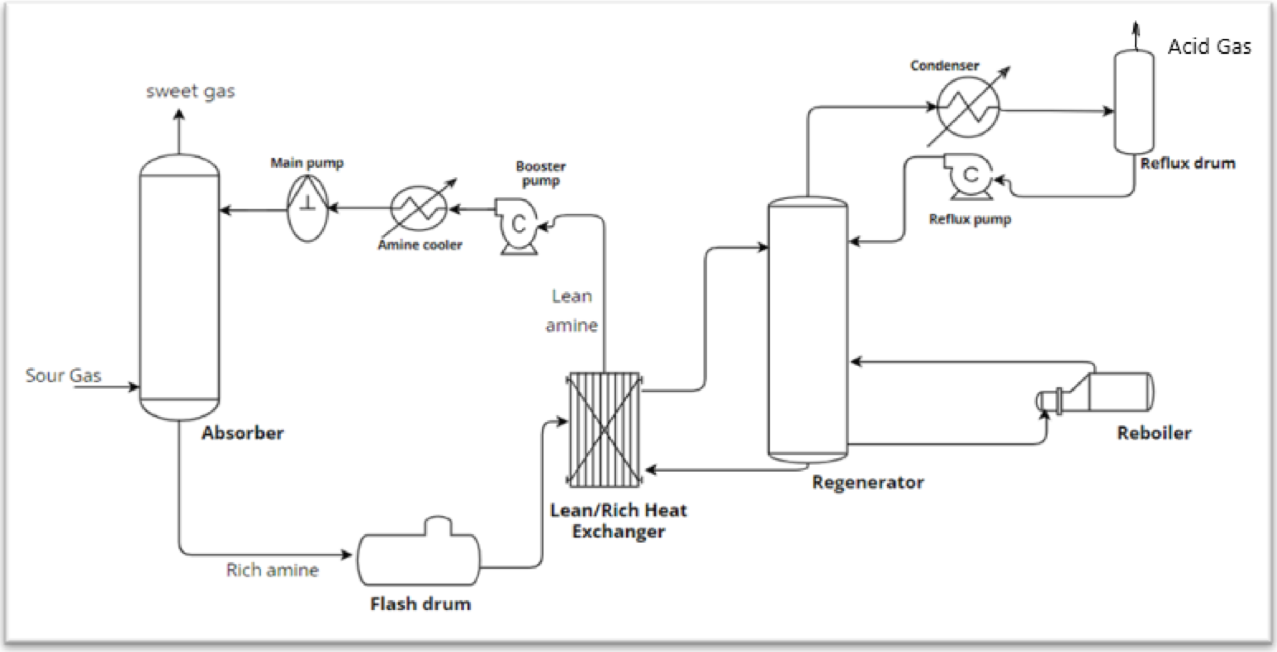

Figure 1. Typical gas sweetening plant PFD.

2.1. Sour gas absorption

Regarding Figure 1, the pressurized sour gas containing H2S firstly enters filter coalescer where any entrained hydrocarbon liquids are removed and drained to oil separation unit avoiding foaming in absorber. Then sour gas leaves from the top of the filter coalescers and heated to by heat exchange with the sweet gas stream from the top of the sour gas absorber. The heated gas then enters the bottom of the absorber below the lower packed section. The composition of gas feed to the absorber is shown in Table 1. The sour gas passes upwards through the column meeting a counter current flow of lean amine solution which absorb H_2S from the sour gas. The absorption process take place within the absorber is exothermic chemical reaction. The Acid gas loading depends on many factors such as operating pressure, absorber temperature, amine type and concentration. Due to low solubility of acid gases in alkanolamines at high temperature, it is preferable to absorb acid gases at low temperature. On the contrary, acid gas absorption is more effective at high pressure due to the higher diffusion rate of acid gases in amine solution [15].

At the top of the absorber the gas is washed by demineralized water to minimize amine carry over. Sweet gas exits from the top of the absorber and passes through the sour /sweet exchanger where it is cooled before entering the sweet gas Knockout (KO) drum where condensed water is separated and drained to the rich amine flash drum. Then sweet gas flows from the top of the sweet gas KO drum to the hydrocarbon and water dew point package for hydrocarbon and water dew pointing. The rich amine produced in the sour gas absorber is sent to the rich amine flash drum.

Table 1. Composition of the feed gas.

Component	Mole fraction	Component	Mole fraction
Methane	0.9846	n-Hexane	0.0001
Ethane	0.0033	n-Heptane	0.0001
Propane	0.0005	Toluene	0.0001
i-Butane	0.0005	CO_2	0.0085
n-Butane	0.0002	H_2S	0.0008
i-Pentane	0.0002	H_2O	0.0001
n-Pentane	0.0001	Nitrogen	0.0009

2.2. Rich amine regeneration

The rich amine solution flows to the rich amine flash drum which operates at 7 barg where dissolved gases are separated. Rich amine leaving the flash drum is heated to approximately 95 °C by heat exchange with hot lean amine from the amine regenerator. The hot rich amine flows to the amine regenerator entering on tray 5 from above. The regenerator is a trayed column containing 24 trays in which H_2S, and other contaminants are stripped from the rich amine by means of the stripping gas generated in the steam heated amine regenerator reboiler. The regenerator overhead gas passes to condenser where it is cooled before entering the amine regenerator overhead reflux drum. Acid gas leaving the reflux drum flows to the Sulphur recovery unit. Liquids separated in the reflux drum are pumped to the top of the regenerator. Lean amine solution leaves the bottom of the amine regenerator. The energy required for stripping is provided by the regenerator reboiler. The steam condensate from reboiler passes to the steam condensate drum from where the condensate is discharged to the low-pressure condensate header.

2.3. Lean amine recycling

Lean amine solution leaves the bottom of the amine regenerator is cooled in the lean/rich amine exchanger and pumped by the lean amine booster pumps to the lean amine air cooler. In order to avoid any accumulation of heavy hydrocarbons and amine degradation products which causes foaming, a portion of the circulating lean amine stream i.e., about 15 % mass flow, is fed to the lean amine filtration package. The lean amine filtration package consists of a pre-filter, an activated carbon filter and a post filter. The filtered lean amine is then mixed back into the main flow and the total stream is pumped by the lean amine pumps to the absorber.

3. Modelling and validation

In this paper, an existed giant plant in Egypt has been used for validation of simulation results. The acid gas removal unit (gas train) in the plant contains an absorption column and a regenerator. The absorber is 25.3m in height and has an internal diameter of 2.6 m. The absorber has three packing beds, with 2.75 m in height for each bed, and has four valve trays at the top with spacing of 0.6 m. The regenerator has 24 valve trays with 25.8 m in height. It has an internal diameter of 1.5 m at its top and 2.5 m at its bottom. Table 2 shows the operating conditions of each unit.

Table 2. Operating conditions of the current gas sweetening unit.

Absorption column	
Column pressure, barg	75.2/80 (top/btm)
H_2S in gas feed, ppm	800
Gas feed temperature, °C	25
Amine conc. in solvent, wt.%	46
Inlet lean amine temperature, °C	51
Amine flowrate, kgmole/h	2700
Feed gas flowrate, MMSCFD	395
Regeneration column	
Column pressure, bar	1.5
Condenser temperature, °C	49
Rich feed temperature, °C	98
Bottom temperature, °C	130

In this study, Aspen HYSYS (version 11) has been used for process simulation selecting acid gas chemical solvents package. The validity of the simulation results can be deduced if the plant data and simulation model data are very close so that the difference between them could be neglected. As presented in Table 3, the simulation results are nearly the same compared to the original plant data. This in turn reveals that the introduced HYSYS simulation tool is valid for this study.

Regarding the considered modification of the investigated plant, a part of amine stream is withdrawn from an intermediate stage of the regenerator and used to feed back the absorber. Due to this modification, the reboiler and condenser duties are reduced. However, this action can lead also to increase H_2S concentration in the produced sweet gas due to the semi-lean amine entering the absorber.

Table 3. Simulation results compared to the original plant data.

Parameter	Plant Data	Simulation results
Feed sour gas temperature (°C)	25	25
Feed gas to absorber temperature (°C)	30	30
Feed gas Pressure (bar)	81	81
Feed sour gas flowrate (MMSCFD)	395	395
Sweet gas pressure (bar)	75	74.6
Sweet gas temperature (°C)	30	29.7
Lean amine temperature (°C)	51	51.1
Lean amine pressure (bar)	85	85
Lean amine flowrate (kgmole/h)	2700	2706
Regenerated amine temperature (°C)	130	129
Overhead condenser temperature (°C)	49	49.9
H_2S Concentration in the feed gas (ppm)	800	800
H_2S Concentration in the sweet gas (ppm)	2.2	2.24
H_2S loading (Lean amine)	0.00121	0.00120

4. Results and discussion

To study the impact of the suggested structure on energy consumption, simulation results are evaluated and compared to the plant data considering the H_2S concentration in the produced sweet gas. H_2S concentration must meet the sweet gas specifications (below 4 ppm). The simulations of the original and the modified plants are shown in Figures 2 and 3.

To apply the split-flow configuration on the investigated unit, there are four main parameters that control the efficiency of the retrofitted process; side stream stage and flowrate, the reboiler duty, amine circulation flowrate and H_2S concentration in the produced sweet gas. The effect of these paraments on the studied plant is discussed on the following subsections.

4.1. Effect of side stream stage and flowrate

At fixed amine circulation rate, increasing the side stream flowrate leads to reduce the reboiler duty as the amine flowrate passing through the reboiler is reduced and therefore the total duty will be reduced as shown in Figure 4. On the other hand, H_2S concentration in the produced sweet gas will increase (see Figure 4). This is because the semi-lean amine entering the absorber has acid gases unstripped in the regenerator and subsequently absorption efficiency of the absorber will reduce. The location of the side stream from the regenerator and its flowrate can be optimized by carrying out different sensitivity analysis by HYSYS.

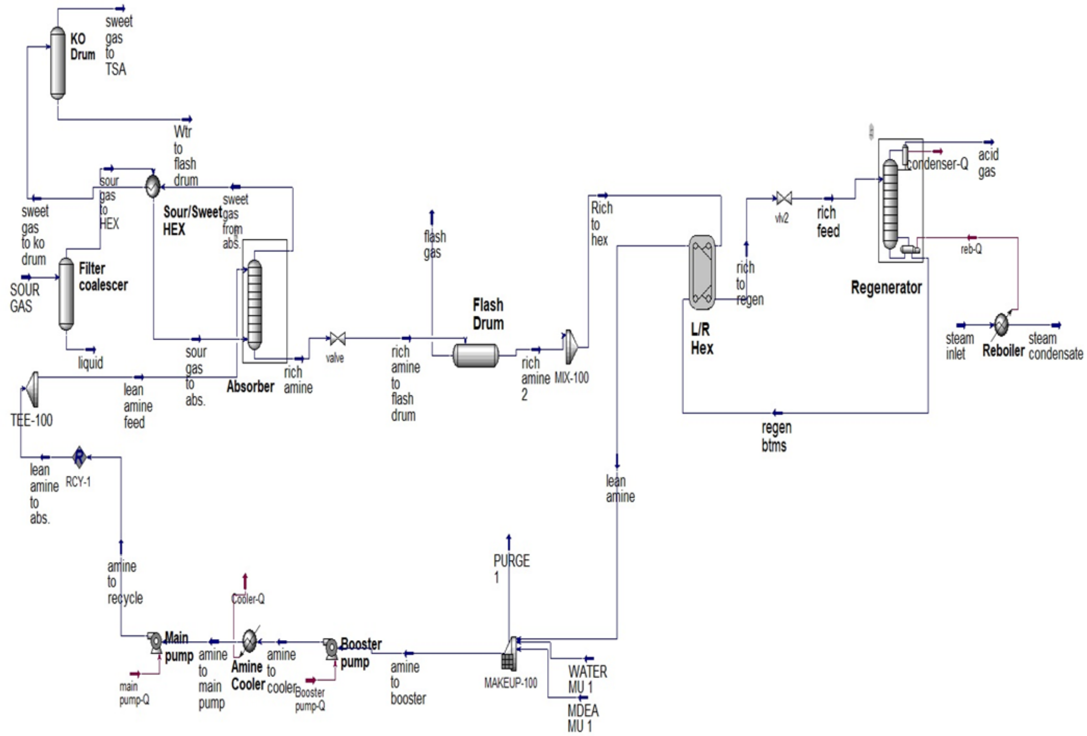

Figure 2: Simulation of the existing plant.

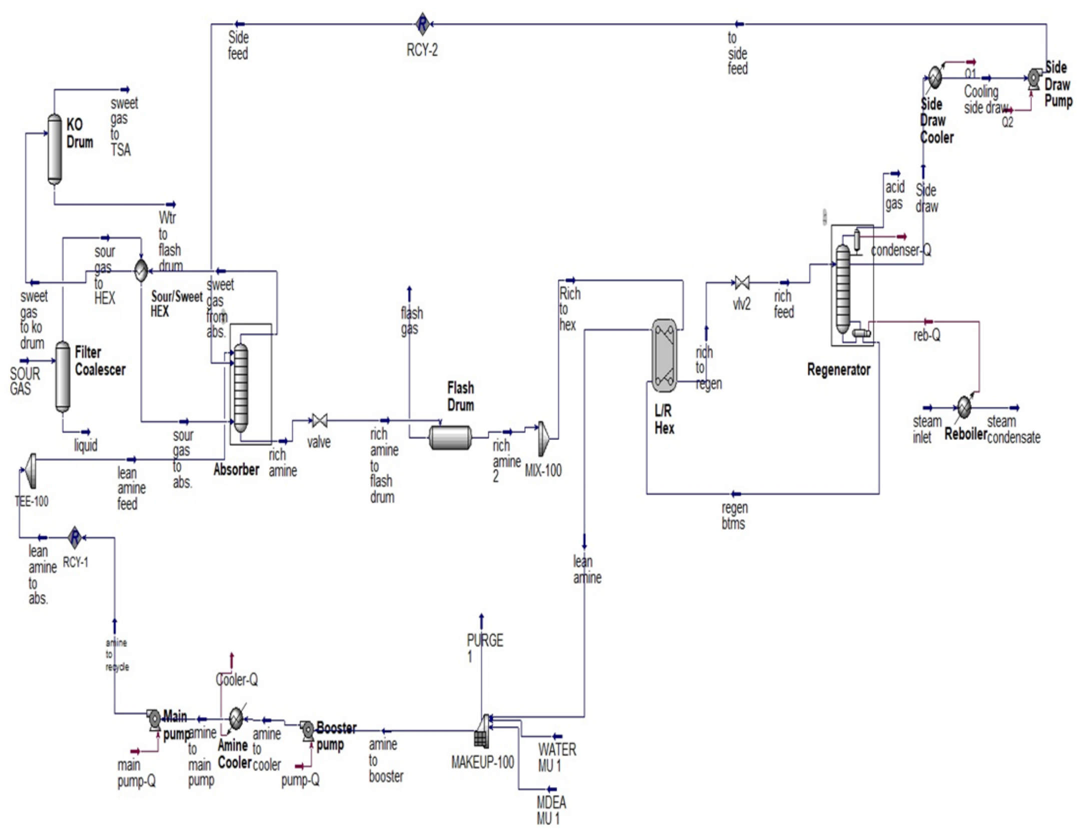

Figure 3. Simulation of the modified split-flow plant.

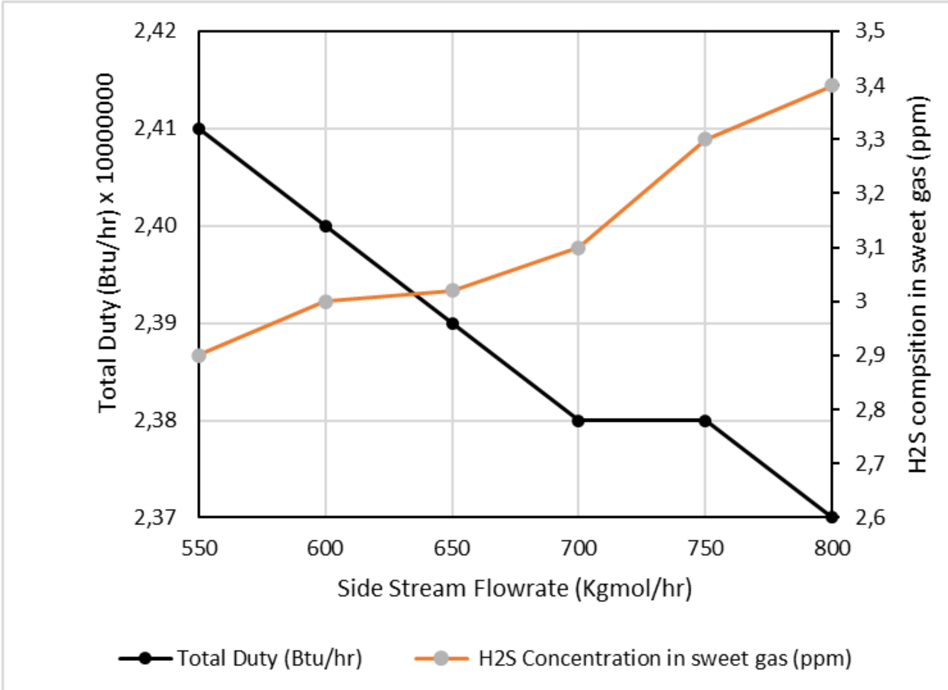

Figure 4. Effect of side stream flowrate on the total energy consumption and H2S concentration in the sweet gas.

4.2. Effect of amine circulation rate

Regarding the forging results, it is required to reduce the H_2S concentration to meet the desired sweet gas specifications. This can be achieved by increasing the amine circulation rate. Figure 6 shows the effect of increasing amine circulation rate on decreasing the H_2S concentration in the produced sweet gas. However, increasing the amine rate leads to increase the reboiler duty due to the increased flow entering the regenerator as presented in Figure 7.

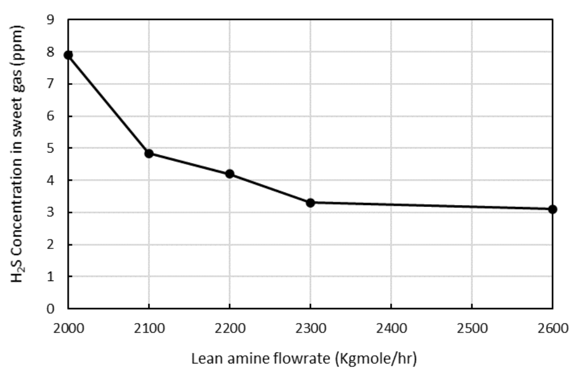

Figure 5. Effect of amine flowrate on H_2S concentration in the sweet gas.

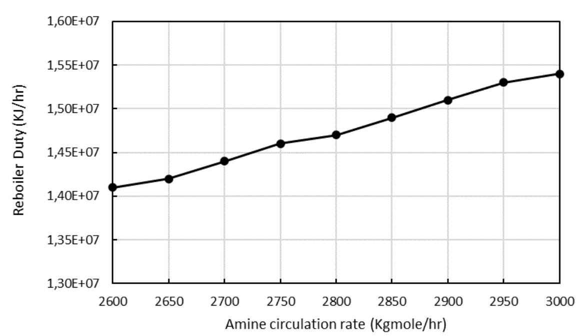

Figure 6- Effect of amine circulation rate on the reboiler duty.

4.3. Reboiler duty

To meet the specifications, reboiler duty is adjusted, and it's expected to be still less than the duty required in the considered case study.

4.4. H_2S concentration in the produced sweet gas

As mentioned before, H_2S concentration in the produced sweet gas must be below the limit i.e. below 4 ppm. To fulfill this requirement, the changing of side stream location (stage) as well as the amine circulation rate were studied. According to the results listed in Table 4, a side stream leaving tray 18 from top of the regenerator with flowrate of 700 kgmole/hr at an amine circulation rate of 3300 kgmole/hr can lead to the optimum results with maintaining H_2S concentration below the limit.

Table 4. Effect of side stream location (stage) and its flowrate on H_2S concentration of the sweet gas.

Amine circulation rate (kgmol/hr)	Side stream location (stage no.)	Side stream flowrate (kgmol/hr)	H_2S conc. in sweet gas (ppm)
3000	18	800	3.5
3600	19	750	3.5
3700	18	800	4.5
3250	18	950	3.9
3300	18	700	3.1
3000	19	900	3.9
3600	19	700	4.2

4.5. Energy analysis

In order to study the effect of the considered modifications on the energy requirements of the investigated gas sweetening plant, energy consumption should be analyzed. Electricity, steam and cooling water are the main utilities used in any amine gas sweetening unit. Electricity is used as the source of power for pumps and air coolers, while cooling water is used for warming down the lean amine. Medium pressure steam (MP) is introduced to the regenerator reboiler as a heating medium [16]. It is found that the regenerator reboiler consumes about 70% of the total energy consumed by the whole unit. This means that decreasing the amount of steam used in the reboiler will lead to a great reduction in the total energy consumption. A comparison between the current and modified plants regarding utilities consumption is presented in Table 5. As shown in Table 5, the modified split-flow structure needs lower amount of steam with a reduction percentage of 11 % compared to the steam required for the original plant. The results also show that electricity consumption has been increased by a small portion due to the more power required in the modified structure.

Table 5. Utilities consumption of the current and modified plants.

Utility type	Rate		Cost (USD/hr)	
	Current	Modified	Current	Modified
Electricity (KW)	393.83	460.23	30.52	35.66
Cooling water (MM gal/hr)	0.168	0.138	20.17	16.67
Steam (K lb/hr)	19.24	17.1	156.67	139.26

According to the results listed in Table 6, energy consumption can be reduced by about 5 million Btu/hr with applying the proposed split-flow structure on the current plant.

Table 6. Comparison of energy consumption between the current and modified plants.

Plant	Reboiler duty (Btu/hr)	Total Energy (Btu/hr)
Current	1.7E+07	2.8E+07
Modified split-flow	1.5E+07	2.3E+07

4.6. Economic analysis

Economic analysis has been done to study the effect of the modified split-flow configuration on the investigated whole unit. Capital and operating costs have been evaluated by Aspen HYSYS. It is found that utility cost contributes to about 55% of the operating cost while steam cost contributes to about 75% of the utility cost. Hence, the main item that makes the great savings in cost is steam which refers to great saving in reboiler duty. Figure 8 shows the utilities cost comparison between the original and modified plants, detailed also in Table 5.

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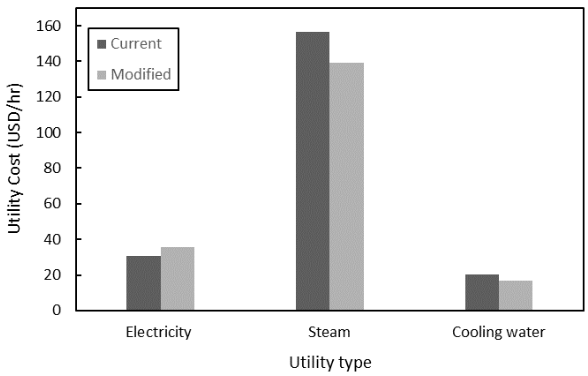

Figure 7. Utilities Cost comparison between the current and modified designs.

Regarding Table 7, the results show that the operating cost of the modified plant is decreased by about 150,000 USD/year compared to the current design. Utility cost reduction has the great contribution of this saving (about 94%) due to reduction of steam consumption in the modified split-flow structure. In the other hand, the capital cost is increased by about 242,000 USD/year in the modified design due to the cost of the required new equipment to be installed to achieve the proposed changes.

Table 7. Cost items of the current and modified plants.

Cost item	Cost (USD/Year)	
	Current	Modified
Capital cost	7,409,770	7,651,700
Operating cost	3,341,270	3,195,200
Utilities cost	1,817,820	1,679,620
Steam cost	1,372,430	1,220,000

As shown in Table 8, at the end of the second year, the net saving is 58,000 USD/year and is increased by 150,000 USD/year in each upcoming year. The calculated payback period of the modified design is 1.7 years. This in turns means that the proposed modifications are economically effective and will effectively increase the profit of the current plant after applying the considered changes [17].

Table 8. The expected cost saving of the modified split-flow structure.

Year	Capital cost saving (USD/Year)	Operating cost saving (USD/Year)	Total cost saving (USD/Year)
1	-242,000	+150,000	-92,000
2	-	+150,000	+150,000
Net saving after 2 years = 150,000-92,000 = +58,000 USD/Year			

5. Conclusion

The aim of this research work is to reduce energy consumption in the investigated gas sweetening plant. To accomplish this aim, a suggested modified structure has been studied. This modification provides circulation of a side semi-lean amine stream. Due to the proposed modification, the reboiler and condenser duties are reduced. Aspen HYSYS version 11 was used to simulate the original and the modified plants. The simulation results show that the energy consumption can be reduced by about 18 % which depends mainly on the reduction of the reboiler duty. The reboiler duty is reduced by about 12 % compared to the original plant. Accordingly, the considered modification is very useful for gas sweeting plants or other similar cases with limited steam production. The economic study shows that the proposed split-flow configuration reduces the operating cost of the process by 150,000 USD/year. The calculated back pay period of the adapted plant is 1.7 years which illustrate the effectiveness of applying the introduced modification in increasing the profits of the current plant.

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