Investigating the effect of semi-lean amine streams on energy consumption of gas purification plant (MDEA base)

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Abstract

This study evaluates the effect of semi-lean amine on energy consumption of gas treatment units of BIDBOLAND refinery (Iran's first gas refinery). To this aim, Aspen HYSYS (V.8.3) software was employed for the unit simulation in rate based method. The results show that as CO_2 content in inlet sour gas is less than 2 mole percent and MDEA solution is used as solvent, using absorption column side stream (split flow) and a flash unit can reduce the unit energy consumption up to 10 percent.

Keywords: Natural gas sweetening, Aspen HYSYS, Semi-lean amine, MDEA, Energy consumption

1. Introduction

Nowadays, one of the most conventional methods of natural gas sweetening is using chemical absorption property of amine solutions which has high energy consumption in spite of various advantages. However, there are several methods to reduce energy consumption and increase unit capacity the most important of which are amine type alteration, column internal modification and process flow diagram which are known as Retrofit Design. Since 1930 when amine solutions were used to remove acid gases in sour gas sweetening process (Figure 1), multiple structures have been proposed for modification and optimization of this process. In 1934, Sholed suggested for the first time a structural modification for early sweetening process optimization [1]. He suggested that a semi-lean stream leaving intermediate stages of the regenerator and its feeding back to the absorption column can reduce energy consumption. In a simple absorption and desorption process (Figure 1), the absorption liquid circulates as one single stream from the bottom of the absorption column to the desorption column, and from the bottom of the desorption column to the top of the absorption column. There are however possibilities to have multiple feeds or draws in both the absorption column and the desorption column. Such configurations are called split-stream or split-flow configurations.

Different alternatives for the split-stream principle are explained in Kohl and Nielsen (1997) and in Polasek et al. (1982) [2, 3]. A survey of process flowsheet modifications for CO_2 removal is given by Cousins et al. (2011) [4]. Energy efficient alternatives are lean amine flash and multiple pressures in the regenerator (Oyenekan and Rochelle, 2006) [5].

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Very few calculations of CO_2 removal from exhaust gas based on split-stream have been found in the open literature. A paper by Aroonwilas and Veawab (2006) is one example [6], but the details in the calculations are not shown. Karimi et al. (2010) use the program Unisim [7] and Cousins et al. (2011) using Aspen Plus show process simulations of different split-flow configurations [8]. The main advantage with a split-flow configuration is a reduction in heat consumption in the regenerator. One reason for the reduction in energy consumption is that only a part of the circulating liquid needs to be fully regenerated. Another explanation is that the driving force especially in the absorption column is reduced so that the absorption column normally has higher driving force when using split-flow.

In 2010, based on the Master Thesis work of Vozniuk [9], the traditional gas purification process with and without split-flow has been investigated with using Aspen HYSYS version (V 7.0), and the Kent-Eisenberg amine model. This work was one of the first studies that were focused on split-flow configuration effect quantitatively. As studies have been so far based on qualitative evaluation of proposed structures, this study has attempted to quantitatively investigate reduction of gas sweetening unit energy consumption using superstructure optimization that provide a semi-lean amine stream in process such as split-flow and flash units. For this investigation, Aspen HYSYS (V 8.3) is used as a process simulator.

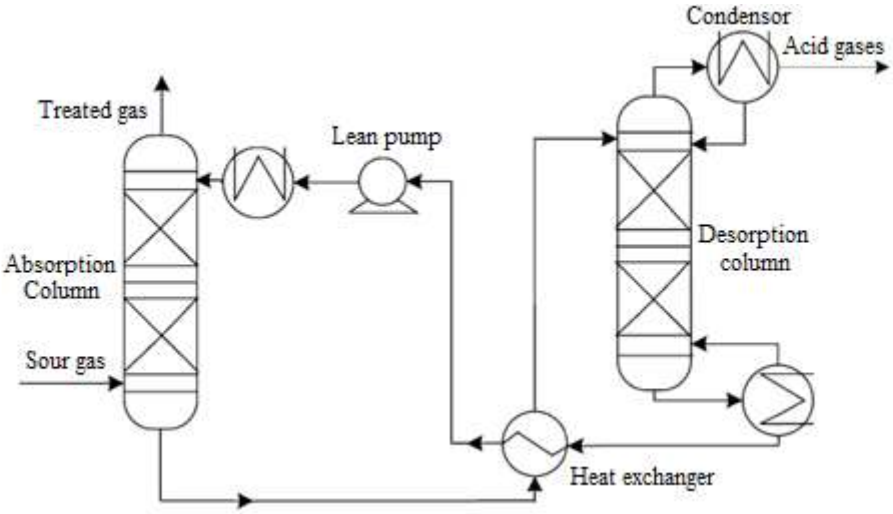

Figure 1. Traditional gas purification process based on amine absorption

2. The Logic of Methodology

As mentioned, one of the most important alterations in order to provide an opportunity for reducing the regenerator energy consumption is using of semi-lean amine stream cycle. For this purpose, there are some many techniques that are summarized into the following items.

2.1. Side Draw from the Desorption Column

This arrangement is known as split-flow configuration. Part of the liquid stream is withdrawn from an intermediate stage of the regenerator column and fed back to an intermediate stage of the absorption column, reducing the reboiler and condenser duties. However, this 'semi-lean' absorbent is less pure than the lean solvent produced in the regenerator column reboiler, and is therefore less able to absorb acid gases. Thus there are trade-offs between the quality of the sweet gas and energy demand.

2.2. Flash Unit

The absorption column operates at a high pressure, while regenerator takes place close to atmospheric pressure. An intermediate flash unit can exploit this pressure difference to provide an energy efficient method of removing some of the acid gases from the rich solvent stream. Therefore, using this additional structure also provide semi-lean amine which is partly regenerated.

3. Modeling and Validation

In this paper, a real life case study (BIDBOLAND gas refinery, Iran) has been used for validation of simulation results. The entire refinery has four parallel gas treatment units (GTU) with 4 absorbers and 4 regenerators. The absorber has an internal diameter of 2.896 meter. Each bed is 6.5373 meters in height and filled with plastic random packing (2-inch Pall rings). The distillation column has 17 sieve trays and internal diameter of 3.9624 meter. Based on tray spacing of 27 inch, the height of column is 11.6586 m. Table 1 shows the current operation conditions of mentioned units.

Table 1. Current operation conditions of BIDBOLAND gas refinery units

Absorption Column		**Regenerator Column**	
Column Pressure, bar	54	Column Pressure, bar	1.4
H_2S in Gas Feed, ppm	1950	Condenser Temperature, ºC	33.0
CO_2 in Gas Feed, mol%	1.74	Feed Temperature, ºC	93.60
Gas Feed Temperature, ºC	30.0	Bottom Temperature, ºC	116.70
Amine Conc. in Absorbent, wt%	40		
Inlet lean Amine Temperature, ºC	34		
Amine Flow Rate, kmol.h^{-1}	4615		
Feed Gas Flow Rate, kmol.h^{-1}	15860		

The validity of the simulation results depends heavily on selection of equilibrium and process model used in simulation. In this study, the ACID GAS thermodynamic package and ELECNRTL package (PMDEA Data package) are selected for process simulation in Aspen HYSYS (V 8.3) and Aspen Plus (V 8.2), respectively. The simulation results and operating data of the BIDBOLAND treatment unit have been provided in Table 2.

Table 2. Simulation results of BIDBOLAND GTU using ELECNRTL and ACID GAS packages

	Plant data	**ACID GAS**	**ELECNRTL**
H_2S in Sweet Gas, ppm	4.00	4.02	3.12
CO_2 in Sweet Gas, mole %	1.1065	0.9834	1.4893
Lean Amine Temperature, ºC	21.20	20.81	20.67
Acid Gas Loading*(Lean amine)	0.328	0.327	0.294
Reboiler Duty, Btu.hr^{-1}	1.13×10^{8}	1.02×10^{8}	9.94×10^{7}

*moles of acid gases per mole of amine

As seen in Table 2, ACID GAS Package which has been inserted in Aspen HYSYS (V 8.3) software simulated the treatment unit with an acceptable accuracy and this simulator is used for the following investigation steps.

4. Results and discussion

In order to analyze the effect of proposed configurations on energy consumption, simulation results of each structure are evaluated separately.

4.1. Split- flow

According to energy balance, if the Amine circulation rate is fixed, using the split-flow configuration will reduce energy consumption of the reboiler. On the other hand, in case of a side stream leaving from upper stages of the regenerator column which has richer amine compared to the lower stages, higher amine circulation rate is needed to consider H_2S limit in the sweet gas stream. And as side stream leaving from lower levels that has higher potential for gas sweetening in absorption column compared to the former mode, lower amine circulation rate will be required. However, the reboiler duty is more sensitive to amine circulation rate compared to semi-lean side stream stage. Thus, according to the results in Table 3 and Figure 2, a side stream leaving tray 19 of the regenerator with the rate of 2500 kmol/hr leads to minimum energy consumption.

Table 3. Effect of side stream stage and its flow rate on the energy consumption

Amine Flow (kmol/hr)	Side stream Rate(kmol/hr)	Stage of Side stream	Rich Loading	Loading of Side stream	Total Energy (Btu/hr)
2830	2300	18	0.4261	0.02484	123408093
2627	2300	19	0.4454	0.02197	121831973
2777	2400	18	0.4335	0.02522	123576531
2560	2400	19	0.4514	0.02230	121569940
2762	2500	18	0.4271	0.02544	123790928
2522	2500	19	0.4481	0.02254	121484369
2752	2600	18	0.4228	0.02567	124274162
2477	2600	19	0.4500	0.02284	121531343
2740	2700	18	0.4215	0.02594	124924927
2451	2700	19	0.4448	0.02306	121653625

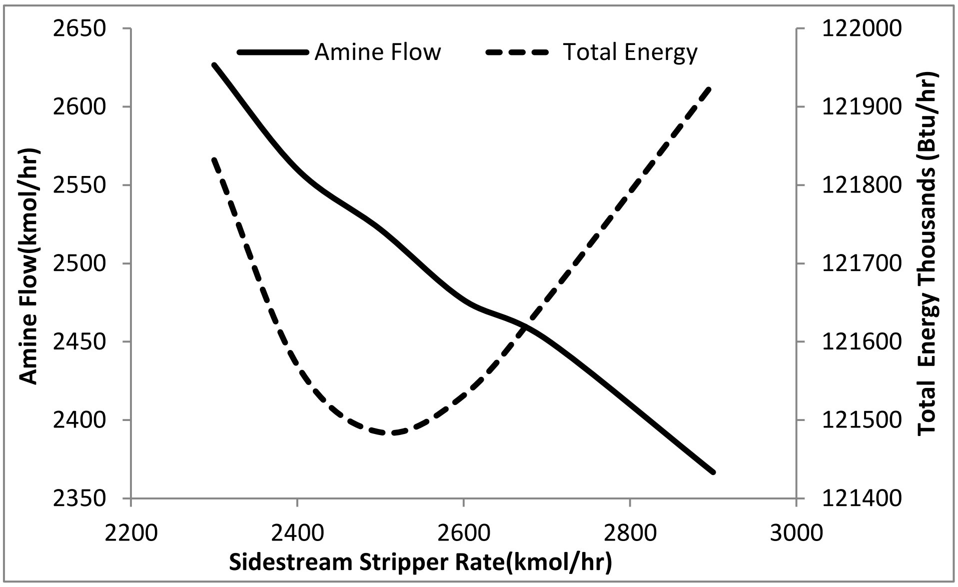

Figure 2. Effect of side stream flow rate leaving stage 19 on the amine circulation rate and energy consumption (H_2S limit: 4 ppm)

According to results presented in Table 4, using the Split-Flow configuration (Figure 3) in BIDBOLAND refinery can reduces the energy consumption about 10 million Btu per Hour compared to current configuration.

Table 4. Comparison of unit energy consumption with and without split-flow configuration*

Structure Type	Amine Flow Rate (kmol/hr)	Side stream Rate (kmol/hr)	Reboiler Duty (Btu/hr)	Total Energy (Btu/hr)
Current Configuration	4615	-	112744989	132415338
Split-flow	2522	2500	103574975	121484369

*H_2S limit: 4 ppm

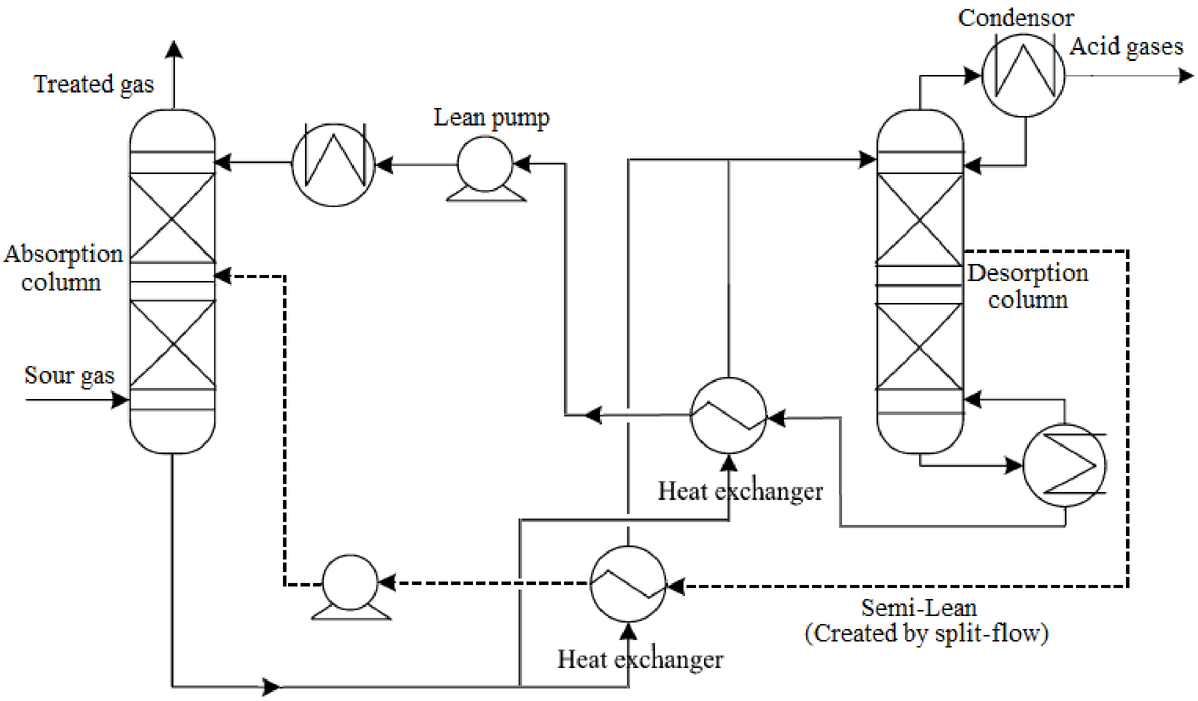

Figure 3. Gas purification process (MDEA base) combined to split-flow configuration

4.2. Using flash unit

Using flash unit for creating semi-lean amine, removed a part of acid gases from rich amine, reduced feed entering the regenerator column and in turn reduced energy consumption of the reboiler. On the other hand, using this unit leads to decreasing of the ultra-lean amine entering the top of the absorption column and in turn reducing absorption of acid gases. These two mutual effects create optimum temperature and stage for feeding semi-lean amine to the contactor column.

In order to remove acid gases from rich amine in flash unit, its temperature had to be increased which was done after pre-heating in lean-rich amine heat exchanger to be according to energy integration principles. In order to increase absorption efficiency, semi-lean amine stream temperature leaving the flash unit was also reduced by an air cooler and according to the sour gas temperature (20°C) and allowed temperature approach (8-15°C) it was set to 28°C to prevent foaming in the column. Entering of semi-lean amine from the top of the column reduces the solvent purity and in turn acid gases absorption rate. At the same time, entering of semi-lean amine from the intermediate stages of the column reduces contact time required for absorption of H2S. Simulation results of new process (split-flow configuration, flash unit structure, Figure 5), according to Table 5 and Figure 4, show that combining these structures increases hydrogen sulfide absorption, reduces corrosion risk and finally reduces energy consumption of the unit. Of course, it should be noted that given the high temperature of the stream entering the flash unit, make-up water has been increased in this structure compared to the previous structures.

Table 5. Effect of flash unit feed temperature and semi-lean feed stage to absorption column on amine circulation rate and energy consumption*

Semi-lean feed stage	Flash unit feed temperature ©	Amine Flow (kmol/hr)	Rich Loading	Reboiler Duty (Btu/hr)	Total Energy (Btu/hr)
10	98	2892	0.3591	100837678	119635106
10	99	2956	0.3527	100099253	119218708
10	100	3142	0.3395	100539336	120342903
11	96	2735	0.3769	100643151	118908196
11	97	2743	0.3739	99897896	118250324
11	98	2818	0.3629	99709836	118318888
12	97	2776	0.3662	100164631	118543610
12	98	2841	0.3582	99865210	118484552
12	99	2932	0.3497	99667283	118694581

*semi-lean amine stream is entered to absorption column with 28°C

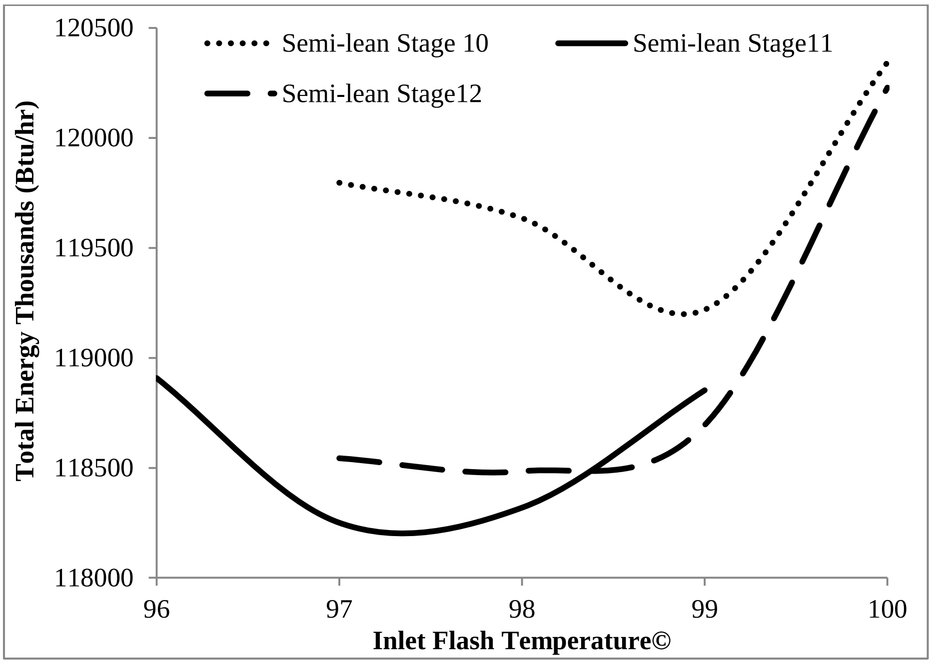

Figure 4. Effect of flash unit feed temperature and semi-lean feed stage to absorption column on energy consumption (semi-lean amine stream is entered to absorption column with 28°C)

Table 6 shows the effect of combining split-flow configuration with flash unit structure on the energy consumption in comparison to split-flow configuration without flash unit.

Table 6. Effect of using flash unit structure and split-flow configuration simultaneously on energy consumption*

Structure Type	Amine Flow (kmol/hr)	Stage of Side stream	Side stream Rate (kmol/hr)	Reboiler Duty (Btu/hr)	Total Energy (Btu/hr)
Split-flow	2522	19	2500	103574975	121484369
Split-flow Flash unit	2743	19	2500	99897896	118250324

*H_2S limit: 4 ppm

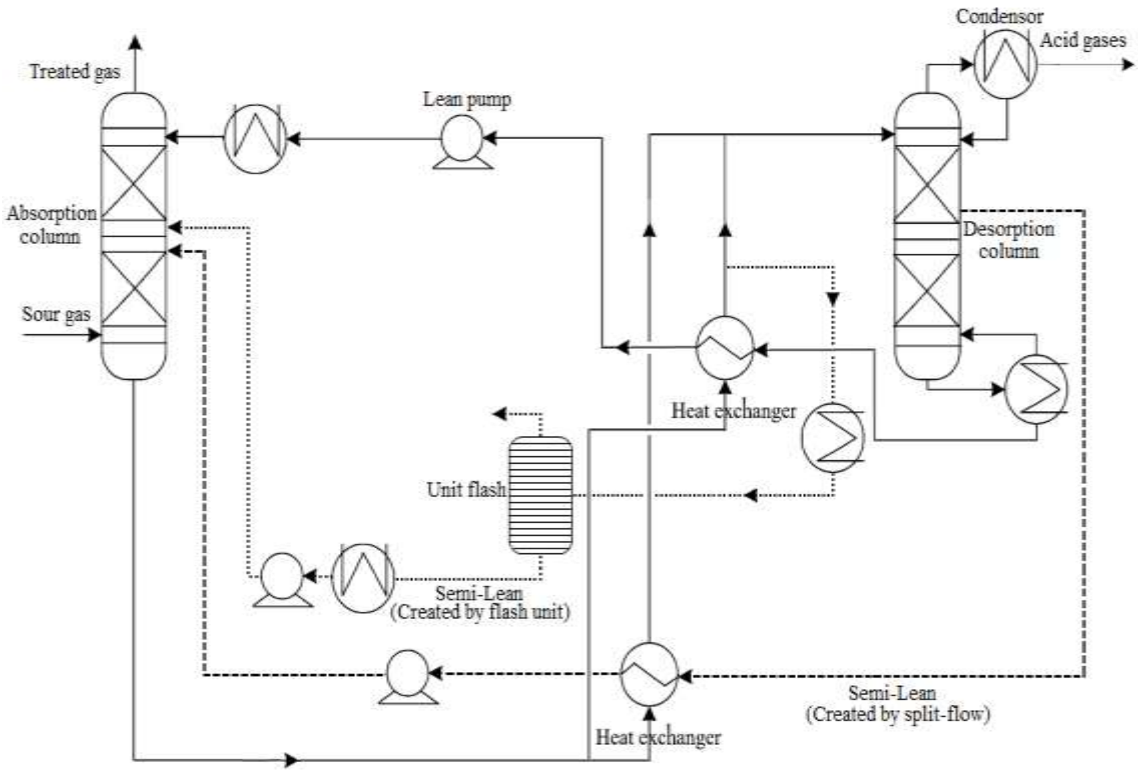

Figure 5. proposed configuration, split-flow combined to flash unit (gas purification process, MDEA base)

5. Conclusion

A review of gas purification process modifications aimed at lowering the energy consumption by providing semi-lean amine circulation highlighted two options, predominantly applicable in the gas processing industry. These options included the split-flow configuration, using flash unit structure on the way of rich amine stream and some heat integration concepts. The process modifications were assessed using commercially available process simulator software (Aspen HYSYS V8.3). Simulation results showed that using these options instantaneously, reduced energy consumption up to 10 percent.

Comparing energy consumption of the regenerator reboiler in the modified process with that in the current state shows that using the modification structures can reduce steam consumption up to 12% which is very important in conditions when steam production should be limited.

Acknowledgments

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