Reducing Energy Consumption in Gas Purification Plants (MDEA base) by Retrofit Design

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Abstract

This study evaluates the effect of Structural modifications 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 percent and MDEA solution is used as solvent, using multiple feeds to the absorption column, static mixers and absorption column sidestream cannot reduce energy consumption level; while using desorption column sidestream and a flash unit can reduce the unit energy consumption up to 10 percent.

Keywords: Aspen HYSYS, Superstructure optimization, MDEA, Energy consumption, Natural gas sweetening.

I. 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. 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 modification 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]. 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 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 the reduction of gas sweetening unit energy consumption using superstructure optimization. For this investigation, Aspen HYSYS (V 8.3) is used as a process simulator.

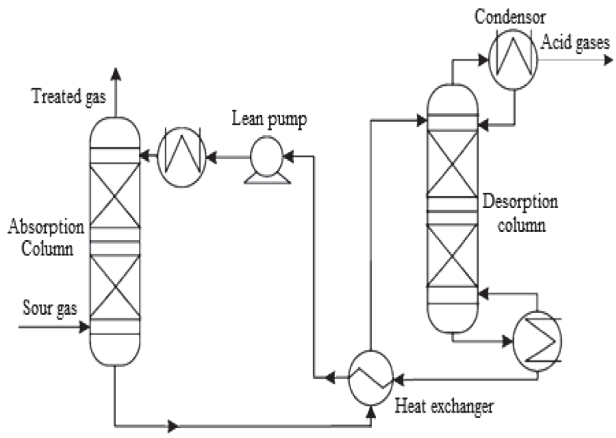

Figure 1.Traditional gas purification process based on amine absorption

II. THE LOGIC OF METHODOLOGY

In this section, the most important alterations in order to optimize sweetening units are summarized briefly.

A. Multiple Feeds to the Absorption Column

In this method, lean amine solution is divided into multiple streams and then enters from different stages into the absorption column. According to the previous research, this makes flat the absorption column's thermal profile and in turn increases the reaction rate of amine with hydrogen sulfide.

B. Split Flow (Absorption Column Sidestream)

In this structure, multiple sidestreams are withdrawn from the absorption column and recycled to the column after cooling. This reduces rich amine rate entering the regenerator column and in turn reduces reboiler and condenser duties.

C. Split Flow (Desorption Column Sidestream)

When the part of the liquid stream withdraws from an intermediate stage of the regenerator column and feeds back to an intermediate stage of the absorption column, on one hand the reboiler and condenser duties will fall down and the other hand this semi-lean solvent is less pure than the ultra-lean stream, and so is less able to absorb acid gases. Because of this, there are trade-offs between the quality of the sweet gas and energy demand.

D. Precontactor (Static mixer)

General structure of this device consists of a pipe with a helix blade inside and fluids are mixed by forced circulation inside this pipe. This device is usually made of materials such as stainless steel and polypropylene. The most important factor encouraging using static mixer is an increase in amine contact time which can increase acid gases absorption like an equilibrium stage.

E. 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.

III. Modelling and Validation

In this paper, an industrial 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 and two sections. Each section is 6.5373 meters in height and filled with plastic random packing (2-inch Pall rings). The regenerator 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.

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 1.Current operation conditions of BIDBOLAND gas refinery units

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

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 therefore used for following investigation steps.

IV. RESULTS AND DISCUSSION

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

A. Multiple Feeds to the Absorption Column

According to low CO_2 content in BIDBOLAND refinery feed gas, using this structure not only made help to increase absorption of acid gases, but also reduced amine residence time in the column and so reduced H_2S absorption.

B. Split Flow (Absorption Column Sidestream)

Split flow reduces rich amine entering the regenerator column. But since in this structure, a part of amine solution withdraws from intermediate stages of the column, if the major reactions occur in bottom stages, acid gas absorption will be reduced due to lack of amine.

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

Parameters	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, (°C)	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

Since the rate of MDEA solution reaction with CO_2 is slower than H_2S reaction, therefore, more amount of H_2S absorb in bottom stages. According to low CO_2 concentration in BIDBOLAND refinery feed stream, the highest reaction occurs in bottom stages of the column. Thus, using this structure will not be effective.

C. Split Flow (Desorption Column Side stream)

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 sidestream 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 sidestream 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 sidestream stage and its flow rate on the energy consumption

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

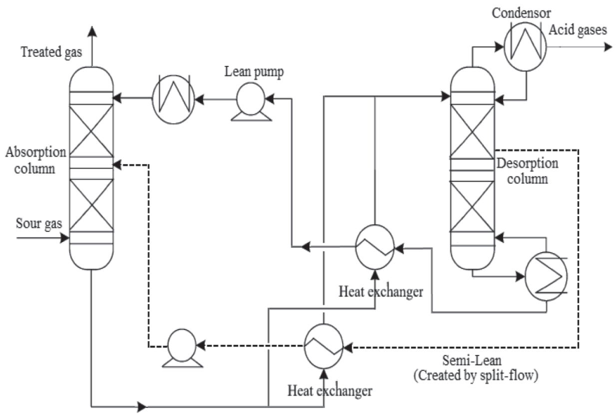

Figure 2.Effect of side stream flow rate leaving stage 19 on the amine circulation rate and energy consumption (H_2S limit: 4 ppm) to split-flow configuration

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)	Reboiler Duty (Btu/hr)	Total Energy (Btu/hr)
Current Configuration	4615	112744989	132415338
Split-flow	2522	103574975	121484369

*H_2S limit: 4 ppm

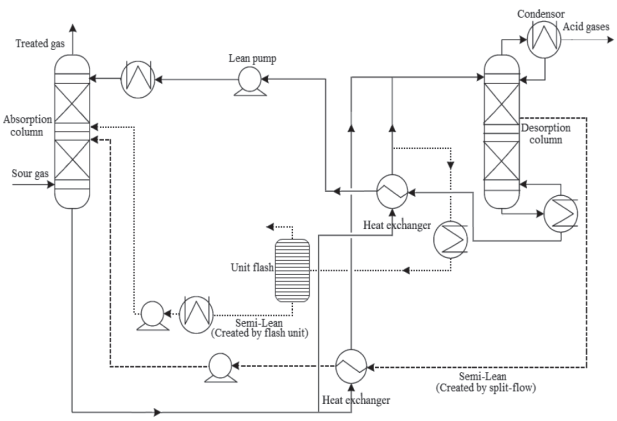

Figure 3.Gas purification process (MDEA base) combined to split-flow configuration

D. Precontactor (Static mixer)

Using static mixer, increases amine contact time and in turn improves absorption of CO_2. However, according to low concentration of CO_2 in BIDBOLAND refinery feed stream, using static mixer is not effective.

E. 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 H_2S. Simulation results of new process(split-flow configuration, flash unit structure, Figure5), 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. However, it should be noted that with increasing the temperature of the stream entering the flash unit, the rate of make-up water will be increased in this structure compared to the previous structures.

Table 6 shows the effect of combining split-flow configuration with flash unit structure on the energy consumption in comparison to split-

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 (°C)	AmineFlow (kmol/hr)	Reboiler Duty (Btu/hr)	Total Energy (Btu/hr)
10	98	2892	100837678	119635106
10	99	2956	100099253	119218708
10	100	3142	100539336	120342903
11	96	2735	100643151	118908196
11	97	2743	99897896	118250324
11	98	2818	99709836	118318888
12	97	2776	100164631	118543610
12	98	2841	99865210	118484552
12	99	2932	99667283	118694581

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

Table 6.Comparison of unit energy consumption with and without split-flow configuration*

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

*H_2S limit: 4 ppm

flow configuration without flash unit. As can be seen, this combination will reduce further the energy consumption.

V. 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

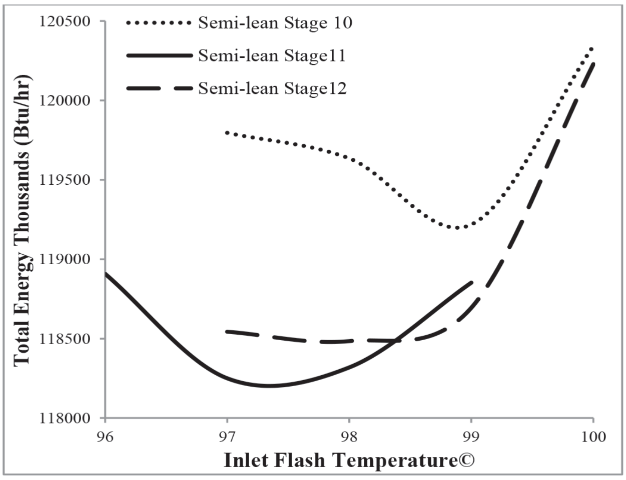

Figure 4. Effect of flash unit feed temperature and semi-lean feed stage to absorption column on energy consumption (semi-lean amine stream is entered to absorption column with 28°C)

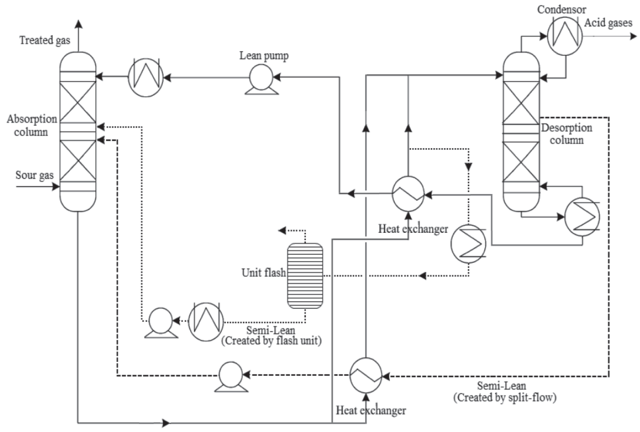

Figure 5.Proposed configuration, split-flow combined to flash unit (gas purification process, MDEA base)

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.

Acknowledgment

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کاهش مصرف انرژی در واحدهای شیرین‌سازی گاز طبیعی توسط محلول MDEA از طریق اصلاحات ساختاری

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چکیـــــده

در این مقاله، اثر اصلاحات ساختاری بر میزان انرژی مصرفی واحد تصفیه گاز پالایشگاه بیدبلند (اولین پالایشگاه گاز ایران) مورد ارزیابی قرار گرفته است. بدین منظور، از نرم‌افزار Aspen HYSYS (V.8.3) بر پایه روش مبتنی بر سرعت (rate-based)، برای شبیه‌سازی واحد مذکور استفاده شده است. نتایج نشان می‌دهد، درصورتی که میزان CO2 در گاز ترش ورودی کمتر از ۲ درصد بوده و محلول MDEA نیز به عنوان حلال در نظر گرفته شود، استفاده از برج جذب چند خوراکه، مخلوط‌کننده استاتیکی و جریان جانبی برج جذب، نمی‌تواند منجر به کاهش انرژی مصرفی گردد. این در حالی است که در شرایط مذکور، استفاده از جریان جانبی برج احیاء و یک واحد تبخیر آنی، می‌تواند تا حدود ۱۰ درصد انرژی مصرفی کل واحد را کاهش دهد.

واژگان کلیدی: **Aspen HYSYS**، بهینه سازی ساختاری، **MDEA**، مصرف انرژی، شیرین سازی گاز طبیعی