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# Energy Efficiency Enhancement in Amine Unit by Application of Multiple Lean Amine Streams in Amine Contactor

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**Abstract:** Nowadays, natural gas is used as a reliable energy resource around the world. Usually, natural gas requires sweetening processes before consumption and amine units are widely employed for this purpose. Amine unit is used for the separation of acid gases, such as H2S and CO2, from natural gas by means of amine solutions. Energy consumption of amine units is significantly high, due to considerable heating and cooling requirements, and practical methods that reduce energy demand are of interest. In this manuscript, a real amine unit of a gas refinery in Iran has been simulated and simulation results have been compared to actual data, available from the real unit and engineering documents. Simulation results have been found in good agreement with actual industrial data. After simulation validation, the application of multiple inlet amine lines to the absorption column has been examined by several simulations and the optimum location of amine entrance to amine contactor has been investigated. Research results have revealed that by the correct application of multiple lean amine streams, amine circulation rate can be reduced and 11% energy consumption reduction can be achieved. This study has been performed based on actual plant conditions without the usual simplifications used in similar studies.

**keywords:** Amine Contactor; Lean Amine, Rich Amine; Simulation

## 1. Introduction

Natural gas is a clean and reliable energy resource that is widely used around the world. Governments and industries are looking for low contaminated energy carriers and as a result, natural gas has gained much attention. Indeed, the contamination caused by natural gas per each energy unit is almost 24% and 42% less than those of petroleum and coal, respectively (Faiz & Al-Marzouqi 2011).

Natural gas is a combination of gaseous hydrocarbons and its compositions and impurities are different based on its geographical source around the world. Sour gas is referred to as a natural gas containing contents such as hydrogen sulfide ($H_2S$) and Carbon dioxide ($CO_2$). Usually, natural gas streams with $H_2S$ concentration of more than 5.7 $mg/m^3$ or 3.8 ppm are considered as sour gases that require treatment prior to consumption by end-users. $H_2S$ is a very toxic combustible gas that can lead to many damages such as catalyst de-activations and corrosion of industrial facilities. Also, a high concentration of $H_2S$ is lethal to mankind. Moreover, $CO_2$ can also result in numerous drawbacks including inefficiency of industries and disorders in storage and transfer of gaseous products (Faiz, El-Naas & Al-Marzouqi, 2011.) (Noeres, Kenig & Gorak, 2003). Hence, the sweetening of natural gas and the separation of acid gases are of much importance. This process is usually performed via an amine solution. The main disadvantage of using amine for gas sweetening is the high energy demand for achieving the desired sweetening level as well as high repair and maintenance expenses of the amine unit which consumes about 25% of the total energy and is dedicated to the control of corrosion (Notz, Mangalapally & Hasse, 2012) (Tavan, Gholami & Shahhosseini, 2016). Several researchers and engineers have studied amine units to improve

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available disadvantages and in this regard, professional simulation tools have been widely used. Some of the most important aspects have been reviewed hereunder.

In 2009, Plaza, Chen, and Rochelle proposed two series of separators and investigated the mass transfer ratio of liquid to gas. They concluded that the application of a stripper will decrease the $CO_2$ content of the sweetened gas by 10% and also reduce the energy required by inter-coolers significantly (Plaza, Chen & Rochelle, 2009).

In 2011, Kumar, Lim, Kwon, Choi & Moon have employed HYSYS software to simulate the process of eliminating $CO_2$ and $H_2S$ from sour gas using a mixture composed of amines and ionic solution. They found that the selection of an efficient solvent is the most important parameter for achieving highly efficient plants. They have shown a mixture of 40% methyldiethanolamine (MDEA) and 5% diethanolamine (DEA) is much more efficient that 40% MDEA alone (Kumar, Lim, Kwon, Choi & Moon, 2011).

To purify gas streams with high $CO_2$ contents, application of split-flow amine have been investigated by Bae, Kim & Lee (2011). In this study, the sweetening of natural gas has been simulated by the Aspen Plus simulator and split-flow has been applied at various $CO_2$ concentrations. It has been reported that the amine split-flow process can decrease energy consumption in comparison with the traditional amine process in separation units, especially at high concentrations of $CO_2$ in the inlet gas (Bae, Kim & Lee, 2011).

In 2012, Salkuyeh and Mofarahi have compared the $CO_2$ separation performance from gas streams at various conditions by using monoethanolamine (MEA) and diglycolamine (DGA), and have designed a real unit with the lowest energy requirements. According to their results, DGA is the best solvent at low $CO_2$ concentrations (Salkuyeh & Mofarahi, 2012).

Application of amines and ionic liquids mixtures have been investigated by Satish, Jae & Il (2014). In this study, researchers have shown how the application of ionic liquid can improve the absorption performance of amines (Satish, Jae & Il, 2014).

In 2014, Abkhiz, Heydari, and Taheri compared the performance of multi-feed amine design with other traditional design options. They investigated the sweetening unit of Fajre Jam refinery which uses alkanolamine solution for gas sweetening and re-simulated the unit with the multi-feed method. High total efficiency, lower operational temperature, the fewer number of tower trays and significant reduction of the expenses were among the advantages of this method, making it a suitable choice for other gas refineries and improvement of sweetening quality (Abkhiz, Heydari & Taheri, 2014).

Three alternate designs (i.e. split-flow, recompressed stream and combination of these two designs) have been studied and simulated with Aspen HYSYS simulation software and compared with a standard amine unit design from an energy consumption point of view (Lars, Terje, Christian, Sven, Marius, Ronny, Iselin & Erik, 2014).

The main amine unit of Lekhwair refinery has been investigated considering main operating parameters (i.e. lean amine circulation flow rate, temperature, and concentration) and some modifications to increase its profitability and sustainability have been proposed. Studies have been carried out by Aspen HYSYS (Nasir, Sultan & Sagheer, 2015).

In 2015, Ghanbarabadi and Khoshandam have studied different options by employing Aspen HYSYS simulation software to reduce the energy consumption of the Ilam refinery. In their investigations, various amines mixtures were investigated by maintaining the bubble and dew points of outlet gas (Ghanbarabadi & Khoshandam, 2015).

HYSYS software has been used to reduce the energy required by reboilers and water coolers in an amine unit by Abotaleb, El-Naas & Amhamed (2017). They have studied the combination of primary, secondary and tertiary amines resulted in a standard sweetening level and MDEA/PZ mixture was introduced as the best-used solution which reduces energy consumption in the plant and improves gas sweetening (Abotaleb, El-Naas & Amhamed, 2017).

Amine unit of Bidboland refinery has been simulated via Aspen HYSYS. It has been proposed that improving the available design by split-flow amines and a flash system. Researchers have reported a 10% reduction in total energy consumption by using a half-rich amine side flow and a flash system (Sabbagh, Ferdowsi & Shykholeslami, 2017).

In this manuscript amine unit of Shahid Hasheminejad (located in the northeast of Iran), as a case study, has been investigated and it has been shown that how energy consumption in this working unit can be improved. In addition to classic studies and calculations regarding this subject, it has been shown that how the number of amine entrance shall be optimized and optimum actual locations on absorber shall be selected. The actual working condition and turndown ratio of the working plant have also been considered during optimization and plant modification.

## 2. Method

### 2.1. Process Description

A traditional amine unit, with 8.79%mol DEA solution, consisted of one absorber for sweetening and one regenerator for amine regeneration is being used by Shahid Hasheminejad refinery, Iran. In the first stage, sour gas is passed through K.O. drum in which water and impurities are separated and then enters the tower from the bottom and the lean amine solution is fed from the top tray of the tower. After the interaction of these two currents, sweet gas exits from the top of the tower while a rich amine solution is transferred to the amine regenerator unit from the bottom of the tower by passing through a flash tank and heat exchanger. Although gas sweetening will reach to its standard level in this design, the high amount of energy consumed by re-boilers, coolers, and pumps makes this process to be considered as a traditional design requiring optimization. Simplified PFD of amine unit can be found in Fig.1.

## 2.2. Simulation of Working Unit

In this study, the acid gas-liquid treating package of the Aspen HYSYS simulator has been employed for simulation of the gas sweetening unit. At first, the real working unit has been simulated based on the process flow diagram (i.e. PFD) and Heat & Material Balance (HMB) of the unit.

The composition of sour gas has been shown in Table 1.

**Table 1.** Specification of inlet gas

| Parameter | Value |
|---|---|
| Flow Rate (kmol/h) | 7,317 |
| Composition (%mole) | - |
| $CO_2$ | 6.51 |
| $H_2S$ | 3.20 |
| COS | negligible |
| $CH_4$ | 88.92 |
| $C_2H_6$ | 0.49 |
| $C_3$+ | 0.22 |

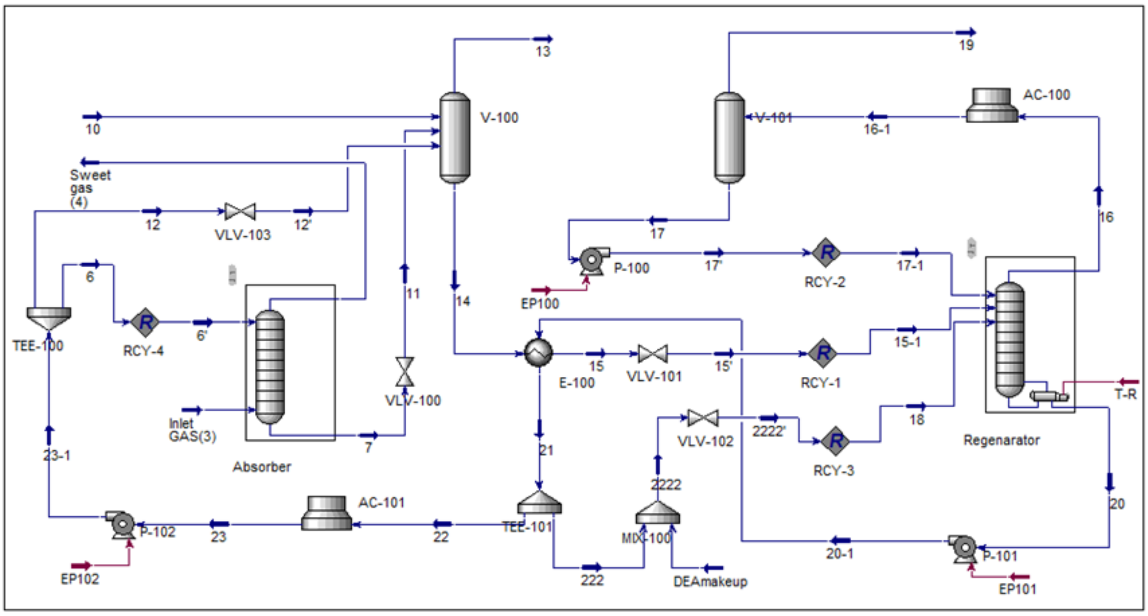


**Fig. 1** Simplified PFD of Amine Unit used in simulation

The main effective parameters in the amine unit include temperature, pressure and amine concentration. These parameters, as well as the flow rate of streams, shaft power of pumps and duty of exchangers have been carefully investigated to assure preciseness of simulation.

## 2.3. New Studies and Optimization

Optimization has been carried out after ensuring the precision of the simulation. The main point of view in this study is to keep high the driving force in various trays by feeding amine streams to the absorption column at several different points while keeping other operational parameters of the sweetening unit constant (i.e. without any remarkable change).

In this regard, and after validation of performed simulation for the working unit, an amine unit is divided into equal portions and introduced to the absorption column at different stages. For each condition, an individual simulation is prepared and after final adjustments, amine circulation rate and energy consumption within the unit have been extracted. Finally, results are compared and optimum conditions can be found. In all stages, all operating parameters, except amine circulation rate, number of amine streams to absorption column and entrance location of Lean amine to amine contactor, have been kept constant. Fig.2 shows the new concept used for the optimization of the amine unit plant.

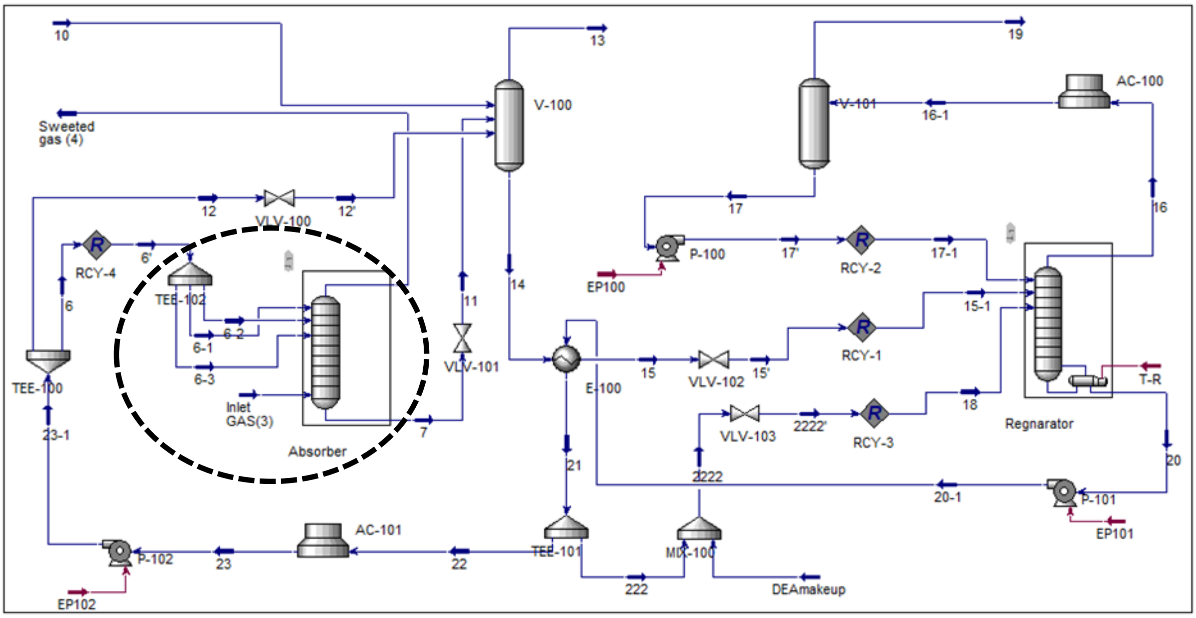


**Fig. 2** Application of three lean amine streams to absorber

## 3. Results and Discussion

Simulation of the working unit has revealed that there are minor differences between actual data of operating unit and simulation outputs. Consequently, the obtained results from simulation files can be trusted.

The actual lean amine stream to amine contactor in the operating unit is 19,255 kmol/h(confirmed by simulation results). By dividing lean amine stream into equal portions and injecting each portion at a specific stage (without changing purification quality and operating conditions), the total required circulating amine can be decreased.

For instance, at the 1st step, the lean amine unit has been divided into two equal streams. 1st portion entered into amine contactor at 1st stage (i.e. top section of absorber) and 2nd portion introduced at a different location. Fig.3 shows the result of this study. Similar studies have been carried out for dividing lean amine stream into 3, 4 and 5 equal portions and Fig.4 represents the results of these studies at an optimum point.

Application of three lean amine streams, for the studied amine unit, seems to be the most feasible concept. The actual number of trays in the absorption tower is 20 trays with an average efficiency of 60% and detail studies on “three lean amine streams scenario” have shown that lean amine shall be divided into three equal streams and injected into amine contactor on 1st, 6th, and 12th trays. Also, results have shown that the injection of lean amine solution lower than 12th tray would not be effective. In other words, below 67% of the contactor’s upper section, amine solution shall not be injected.

Most of the required energy in an amine unit is used for circulating and regenerating the amine solution. As the circulation rate of amine is reduced, lower energy consumption is anticipated. In the aforementioned discussed optimum scenario, amine circulation rate has been decreased 19,255 kmol/h and for the operating plant to 15,123 kmol/h, resulting in lower total energy consumption by the unit. 21.6% reduction in amine solution circulation rate results in lower water and amine consumption as well as lower energy demands by re-boiler, pumps, and coolers. Figures 5, 6 and 7 are showing energy demand reduction in optimized design.

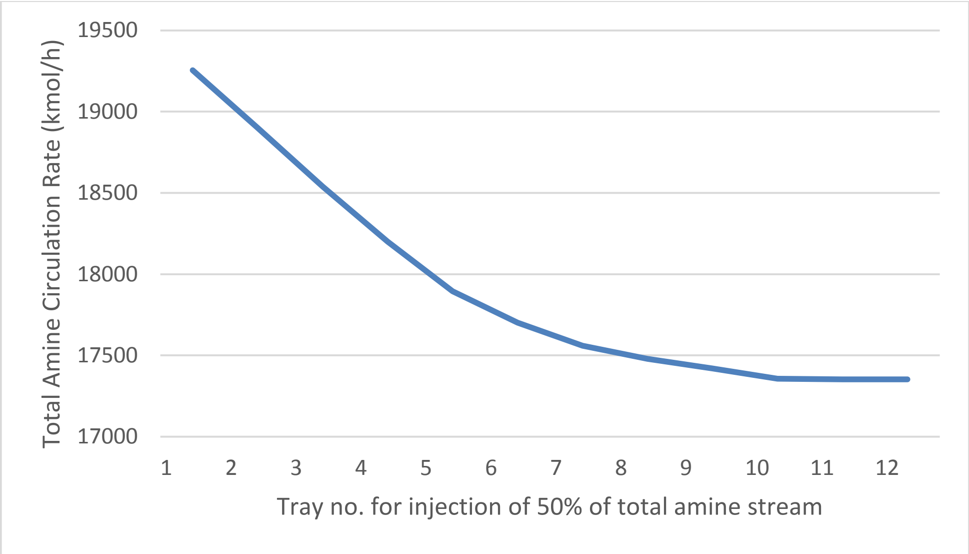


**Fig.3** Application of two lean amine streams into absorber (50% of lean amine solution at 1st stage, i.e. top of the contactor, and other 50% at lower stages) and effect on total amine circulation rate

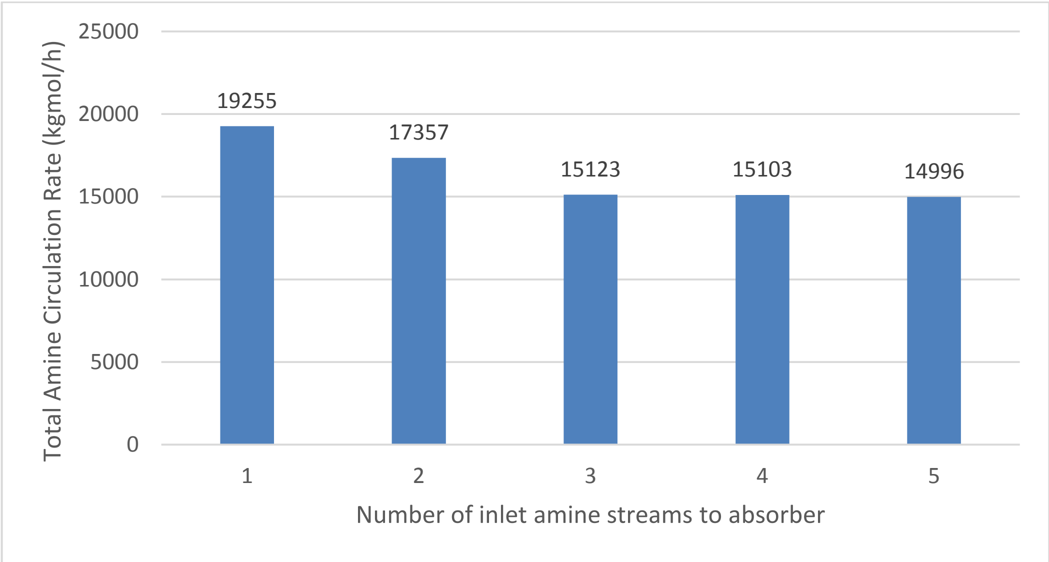


**Fig.4** Changing of the total required amine circulation rate by using multiple lean amine streams.

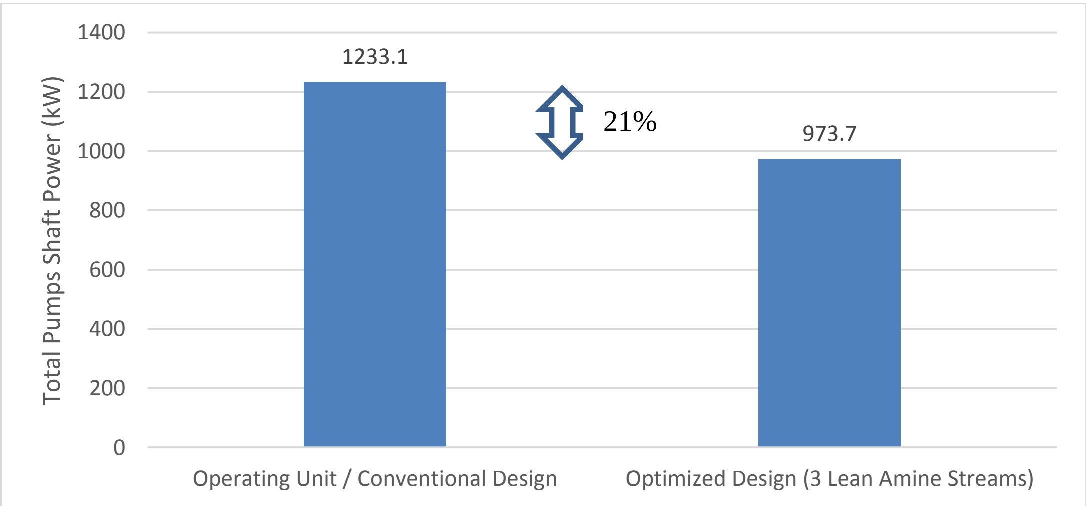


**Fig.5** Comparison of shaft power demand by pumps

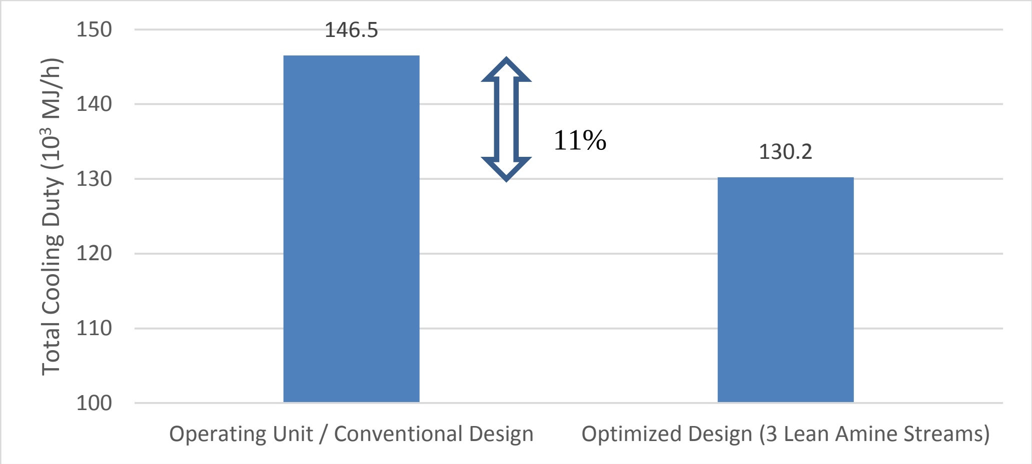


**Fig.6** Comparison of coolers cooling duty

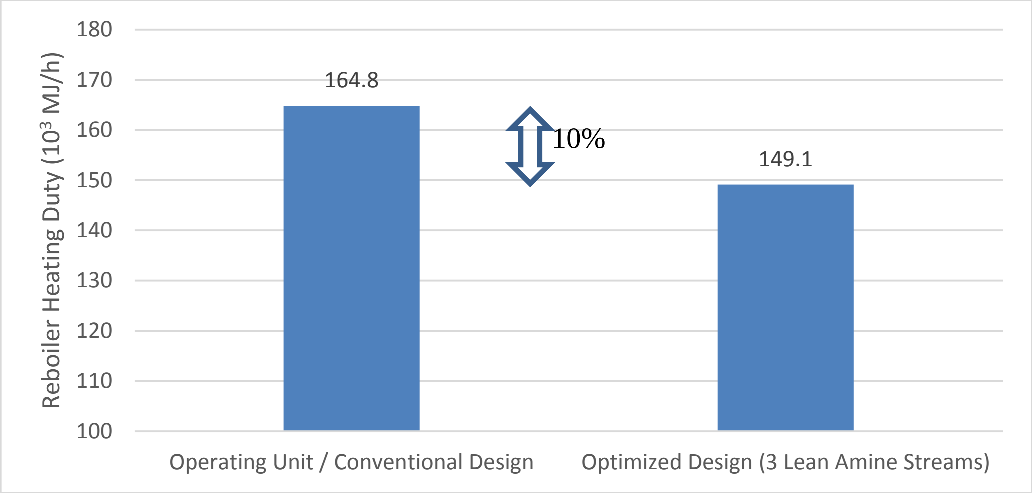


**Fig.7** Comparison of re-boiler heating duty

**Table 2** Comparison of simulation results for treated gas

| Variable | Operating Condition of Working Plant | Simulation of Working Plant | Simulation of Optimized Plant* |
|---|---|---|---|
| Temperature (8C) | 72 | 71 | 71 |
| Pressure (kPa) | 7,250 | 7,250 | 7,250 |
| Molar Flow (kmol/h) | 6,599 | 6,618 | 6,624 |
| **Composition (mole fraction)** | | | |
| $CO_2$ | 1.04E-006 | 1.02E-006 | 0.71E-006 |
| $H_2S$ | 1.45E-007 | 1.43E-007 | 1.05E-007 |
| $CH_4$ | 0.98093 | 0.97998 | 0.98110 |
| $C_2$+ | 7.77E-003 | 7.77E-003 | 7.77E-003 |

* Optimized Plant with 3 Lean Amine Streams

It should be re-emphasized that in all studied scenarios, operating conditions and degree of purification has been kept similar to actual data of working plant and deviations are minor. For instance, Table 2 shows operating conditions and composition of treated gas in the real working plant, simulation of plant and optimized simulation. As can be seen, there are negligible deviations.

## 4. Conclusion

In this manuscript, the amine unit of Shahid Hesheminejad Gas Refinery has been simulated by Aspen HYSYS. After simulation validation, further studies have been performed to show how the application of multiple lean amine streams to amine contactor may improve energy consumption in an amine plant without changing the operating condition and degree of purification, considering the actual working condition, plant turndown ratio and fluid flow in exchangers. By employing three lean amine stream to absorber column it would be possible to reduce amine circulation rate by 22%, approximately. Also, energy consumption by pumps, air coolers, and re-boiler has been significantly decreased. A similar method can be used in other operating amine units to minimize energy consumption. This methodology can also be employed to be a designer to improve new designs.

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