



A Novel Method for Heat Integration of Natural Gas Sweetening Process

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ABSTRACT

The natural gas sweetening unit usually involves an absorption column and a distillation column. The absorption column completely removes H_2S and CO_2 from natural gas, and the distillation column is used to recover the solvent. The main problem is high energy consumption in the gas sweetening process, particularly in the distillation column, necessitating energy optimization of this process. A novel method was used in this study for heat integration of the natural gas sweetening process. To this end, liquid and vapor streams leaving the absorption column entered the top and bottom of the distillation column, respectively. The feed entering the distillation column was preheated by the bottom product. The liquid and vapor streams reduced the cold and hot utilities of the distillation column, and feed preheating reduced the heat duty of the reboiler. The recycled solvent was then pre-cooled by the sweetened gas. According to the results, the proposed method reduced energy consumption by 67%. Moreover, the proposed process could reduce the total annual cost (TAC) of the base process to the maximum value of 66.7%. This reduction in TAC is due to the reduction of operating cost and capital cost by 66.77 and 66.64%, respectively.

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1. Introduction

Fossil fuels are the main fountainhead of energy all around the world (Song et al., 2017). Natural gas will be among the most momentous and famed superseded in the coming decades (Baccanelli et al., 2016). Because of its location in profound subbasement reservoirs, natural gas possesses several non-hydrocarbon components, such as carbon and hydrogen sulfide (H_2S) (Seo et al., 2016). These impurities are unwanted components, which may result in the corrosion of materials and environmental problems, such as global warming and acid rain (Chen et al., 2016). These gases may also cause health problems for humans and even death. The elimination of CO_2 from natural gas can effectively increase the heating value of the final product. (the gas that is sold) and other products (Tavan and Tavan, 2014). Accordingly, the natural gas should be sweetened through various techniques, such as physical absorption, membrane processes, hydrate, cryogenic distillation and absorption using chemical solvents like amines (Mohamadi-Baghmolaei et al., 2021). Gas sweetening with amine solvents is among the important procedures for removing acid gases (Song et al., 2017).

Amines are organic compounds in which nitrogen is connected to the radical chain. In this regard, one of the most common processes is gas sweetening using alkanolamine solutions. As its name indicates, alkanolamine is considered a mix of alcohol and ammonia (Al Hatmi et al., 2019). The difference between various amines is caused by the different numbers of alcohol radicals replaced with hydrogens of ammonia. Today, monoethanolamine (MEA), diethanolamine (DEA), methyl diethanolamine (MDEA), diglycolamine (DGA), and diisopropanolamine are the most important alkanolamines used in natural gas sweetening units (Kohl and Nielsen, 1997). The MEA is typically used due to its availability, relatively low price, and rapid absorption. The cost-effectiveness and high handling capacity of

large amounts of feed are some of the benefits of amine-based absorption processes. (Song et al., 2017).

Gutierrez et al. used MDEA solution to compare a conventional process of natural gas sweetening with an absorption process using recompressed vapor and a membrane process in terms of compression and pump power, total specific heat, CO_2 removal, CH_4 wastes, and capital cost. The process that used a membrane system consumed lower energy than the other two processes by 77% and 72%, respectively. It also emitted less pollution by 80% and 76%, respectively. However, the overall cost of the membrane system was respectively 12% and 5% more than the capital cost of the other two methods. Moreover, the CH_4 waste in this system was higher than the two other processes (Gutierrez et al., 2017). Mohamadi-Baghmolaei et al. studied different combinations of MDEA and DEA to reduce the exergy loss, energy loss, and CO_2 emission in the gas sweetening process. Their outcomes showed that the absorption column and the stripper were accountable for 37% of the total exergy loss and 29% of the energy consumption.

The concentration of DEA plays a crucial role in the exergy and energy management of the natural gas sweetening process. The optimum concentration of amine was found to be 40 wt.%, lowering the total exergy loss from 6.6 MW to 4.8 MW and the energy loss by 36.7%. The CO_2 emission has reached 2893.6 tons per year (Mohamadi-Baghmolaei et al., 2021). Long et al. used heat pump and SHRT methods to propose a novel process for natural gas sweetening with amines. In this process, the latent heat and sensible heat could be circulated using the SHRT method, which resulted in a remarkable improvement in energy efficiency. According to the obtained results, the suggested process could reduce the reboiler duty and operating cost by 62.5% and 45.9%, respectively, compared to a typical gas sweetening process. It also resulted in a 31.2% lower reboiler duty and 22.6% lower

operating cost than the heat pump method (Long and Lee, 2017). Kazmi et al. compared gas sweetening processes with three different solvents, including MEA, DME, and 3MEPYNTF2 (ionic solvent), in terms of exergy, economic and energy. According to the results, the total energy consumed in the three processes equaled 57.45, 30.98, and 13.3 MW, respectively. Moreover, the economic analysis indicated that the ionic solvent led to 83.27% and 73.38% energy saving in TAC in comparison with the other two processes (Kazmi et al., 2021).

Very high energy consumption is the major challenge in the natural gas sweetening process. A large part of energy is consumed in the distillation column where the solvent is recovered. Energy consumption in the whole process was significantly reduced using a novel method. In this method, a liquid stream and a vapor stream leave the absorption column and respectively enter the top and bottom of the distillation column. In this way, part of the heat required in the distillation column is supplied by

these two streams, reducing the heat duties of the reboiler and condenser. The feed entering the distillation column is then preheated by the bottom product, and the solvent recycled to the absorption column is pre-cooled by the sweet gas, significantly reducing the hot and cold utilities of the process. The advantage of this method in the natural gas sweetening process, compared to other heat integration techniques like VRC (Gutierrez et al., 2017), heat pump (Long and Lee, 2017), and SHRT (Long and Lee, 2017), lies in its non-reliance on a compressor, which leads to a decrease in process costs. Hence, the proposed method is anticipated to outperform other heat integration strategies.

2. Case Study

This study focused on the natural gas sweetening process through monoethanolamine solvent.

(Table 1) indicates the feed/solvent qualifications.

Table 1. Feed/solvent conditions

| Process Characteristic | Feed | Solven | |
|------------------------|------------------|--------|-------------------------|
| Temperature (°C) | 30 | 30 | |
| Pressure (kPa) | 3000 | 5000 | |
| Mass flow rate [kg/h] | 75600 | 100000 | |
| | Methane | 0.85 | |
| | Ethane | 0.04 | |
| | Propane | 0.02 | H ₂ O 0.8878 |
| | i-Butane | 0.007 | |
| | n-Butane | 0.006 | |
| Mole fraction | i-Pentane | 0.004 | |
| | n-Pentane | 0.003 | |
| | CO ₂ | 0.03 | |
| | H ₂ S | 0.02 | MEA 0.1122 |
| | N ₂ | 0.01 | |
| | H ₂ O | 0.01 | |

It is worth mentioning that feed/solvent qualifications are identical in both processes.

3. Methods

In this research, the Aspen HYSYS V.11 software was utilized for process simulation, and the Modified HYSIM Inside-Out solver was used to run the solver to enhance the precision. In addition, the Acid Gas-Chemical Solvents equation was applied to the fluid package.

3.1. Process Simulation

This paper evaluated the natural gas sweetening by monoethanolamine solvent with and without heat integration.

3.1.1. The Process of Natural Gas Sweetening by Monoethanolamine Solvent Without Heat Integration

The simulation process of natural gas sweetening using monoethanolamine solvent

in Aspen HYSYS software is demonstrated in (Figure 1). The feed and solvent enter the absorption column from top and bottom in this figure. The upper and lower pressures of the absorption column are 4800 and 4900 kPa, respectively. The top product of the column is sweet gas, and the bottom product is a mixture of solvent and sour gas, which is released from the first column and enters the fifth tray after reaching a temperature of 100 °C. Similarly, the second column consists of 20 trays with 101.3 and 130 kPa pressure on the bottom and top of the column, respectively. The top product of the second column is H₂S and CO₂ and the bottom product contains monoethanolamine and water, which reaches the initial pressure and temperature of the solvent again after passing the pump and cooler and returns to the process beginning.

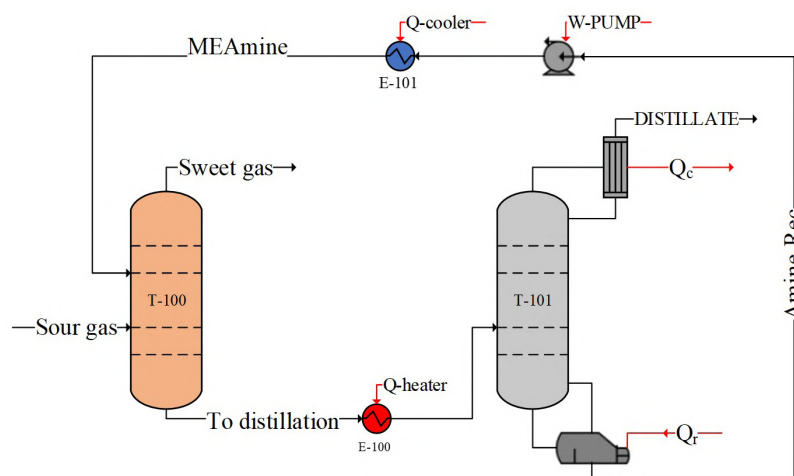


Figure 1. Process of Natural Gas Sweetening using Monoethanolamine Solvent

3.1.2. The Process of Natural Gas Sweetening by Monoethanolamine Solvent with Heat Integration

(Figure 2) depicts the process of natural gas sweetening using monoethanolamine solvent with heat integration in Aspen HYSYS software. The feed and solvent are entered the absorption column from the top and bottom, respectively. The upper and lower pressures of the absorption column are 4800 and 4900 kPa, respectively. The top product of the column is sweet gas, and the

bottom product is a mixture of solvent and sour gas, which is preheated by the bottom product of the second column. Then, the preheated product is entered into the heater to reach 100 °C, finally entering the fifth tray of the second column. Two currents, one in liquid and the other in steam form exit the first column and enter trays 2 and 19 of the second column, respectively,

to minimize the heat duty of the reboiler and condenser. As the prior procedure, the first and second columns contain 20 trays, and the upper and lower pressures of the column are 101 and 130 kPa, respectively. The distillate of the second column (H_2S and CO_2) and the bottom product

containing monoethanolamine and water, are pre-cooled by sweet gas released from the top of the first column and reaches $75\text{ }^\circ\text{C}$ after gaining a pressure of 5000 kPa. Then, this product is cooled to $30\text{ }^\circ\text{C}$ by the cooler and finally returned to the process beginning.

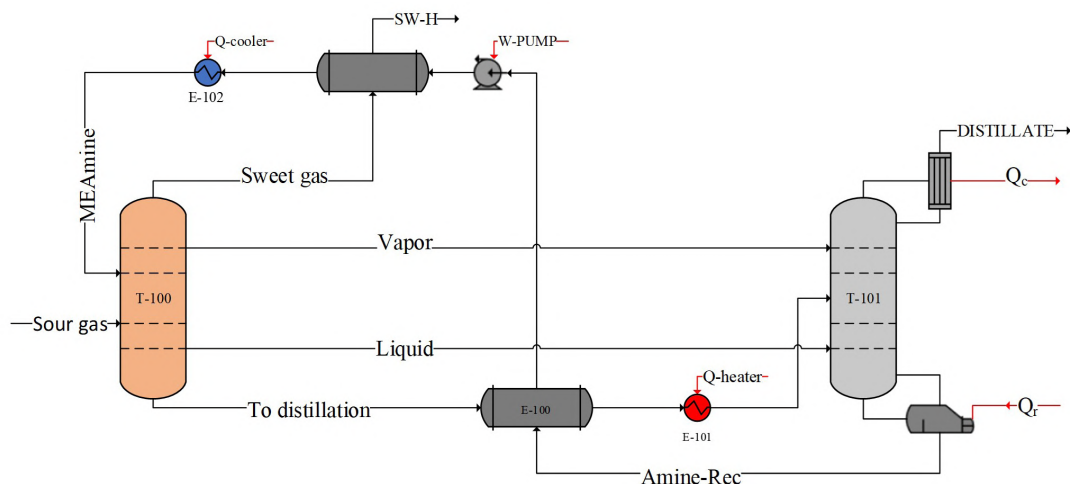


Figure 2. Process of Natural Gas Sweetening using Monoethanolamine Solvent with Heat Integration

3.2. Heat Integration of the Process

In this research, in order to compare the economic cost of the two simulated processes, the parameter of Total Annual Cost (TAC) has been used. The Total Annual Cost is calculated as the sum of the annual operating costs and the annual capital costs. The Total Annual Cost has been calculated through Eq.(1) (Babaie and Esfahany, 2020) In this research, in order to compare the economic cost of the two simulated processes, the parameter of Total Annual Cost (TAC) has been used. The Total Annual Cost is calculated as the sum of the annual operating costs and the annual capital costs. The Total Annual Cost has been calculated through Eq.(1) (Babaie and Esfahany, 2020).

$$TAC = Operating\ Cost + \left(\frac{Capital\ Cost}{Payback\ Period} \right) \quad (1)$$

This paper considers a payback period of 5 years and a man-hour value of 2480 hours. Further information regarding the economic analysis can be found in Appendix A (Babaie and Esfahany, 2022).

4. Results and Discussion

The heat duty of the reboiler and condenser in the two mentioned processes is indicated in (Table 2).

Table 2. Heat Duty of the Reboiler and Condensers

| Heat Duty [MW] | P1 | P1 |
|----------------|--------|--------|
| Q_r | 88040 | 29240 |
| Q_c | 88020 | 29240 |
| Q-heater | 3.053 | 0.8145 |
| Q-cooler | 8.747 | 4.69 |
| W-pump | 0.1882 | 0.1852 |

Q_c and Q_r represent the heat duty of the second column's condenser and reboiler, respectively. In addition, Q-heater, Q-cooler, and W-pump show the heat duty of the heater, cooler, and pump power, respectively.

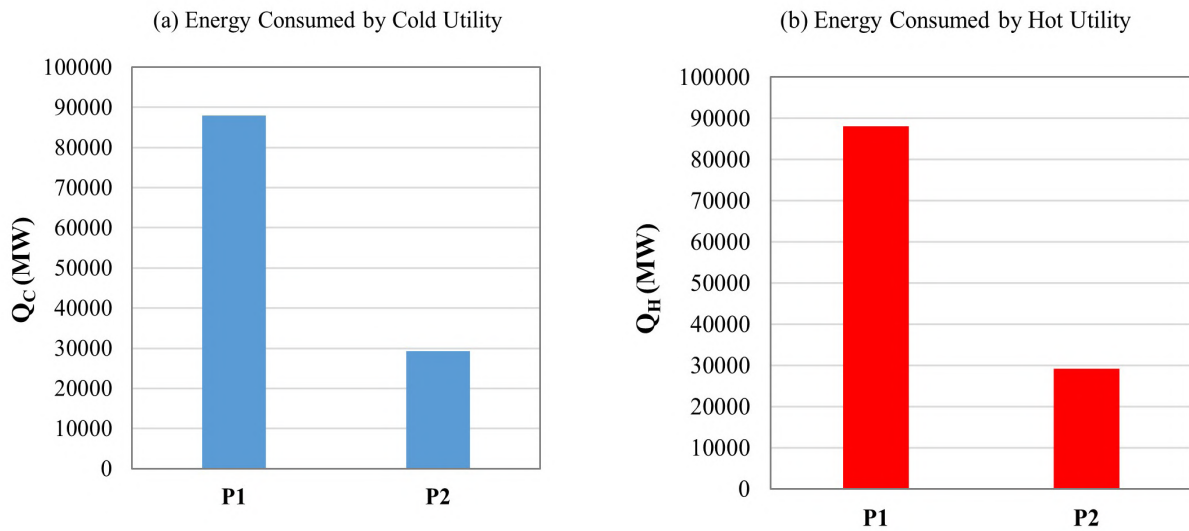


Figure 3. Comparing the Energy Consumption (a) Energy Consumed by Cold Utility, (b) Energy Consumed by Hot Utility

(Figure 3) compares energy utilization in the natural gas sweetening process using monoethanolamine solvent with (P2) and without (P1) heat integration. According to this figure, the gas sweetening process with heat integration consumes less energy than when the heat integration is not utilized. The proposed process demonstrates a significant reduction in both hot utility and cold utility by 66.78 percent and 66.77 percent, respectively, when compared to the base process. Consequently, the overall process energy consumption has been effectively diminished by 67 percent. This reduction is computed by comparing the energy

consumption of the proposed method (which is the sum of the hot utility, cold utility, and pump work) to that of the basic process. In the proposed process, by introducing side streams of vapor and liquid into the upper and lower sections of the stripping column, the amount of reflux vapor and liquid needed in the column has decreased. This leads to a reduction in the heat duty of the reboiler and condenser. Subsequently, in order to decrease the heat duty of the heater and cooler, the feed entering the heater and cooler is preheated and precooled respectively, using the bottom product of the stripping column and the top product of the absorption column.

Table 3. Equipment Sizing Data

| Equipment | Conventional | Heat Integration |
|---|--------------|------------------|
| T-100 height [ft] | 40 | 40 |
| T-100 diameter [ft] | 5.139 | 5.139 |
| T-101 height [ft] | 40 | 40 |
| T-101 diameter [ft] | 873.72 | 405.6 |
| Heat transfer area of heater [ft ²] | 310.52 | 88.12 |
| Heat transfer area of cooler [ft ²] | 4375.36 | 966.83 |
| Feed rate to pump [m ³ /s] | .02766 | .02766 |
| Heat transfer area of heat exchanger E-100 [ft ²] | - | 2035.5 |
| Heat transfer area of heat exchanger E-102 [ft ²] | - | 966.83 |

Based on the economic analysis results, the proposed process significantly reduces the operating cost due to the decrease in hot and cold utilities. Based on (Table 3), the diameter of the stripping column in the proposed process is reduced by approximately 50 percent due to the reduced boilup to the stripping column in the proposed process compared to the basic process, thereby decreasing the capital cost as well. Furthermore, the heat transfer area of the cooler in the proposed process was reduced by

approximately 78 percent because of the pre-cooling of recycled Amine by sweet gas, the distillate product of the absorption column. Owing to these reductions in both operating and capital costs, the TAC in the proposed process is lowered by 66.77% in comparison to the basic process even though two heat exchangers were added to the proposed process. (Figure 4) compares the operating cost, capital cost and TAC in the natural gas sweetening process using monoethanolamine solvent with (P2) and without (P1) heat integration.

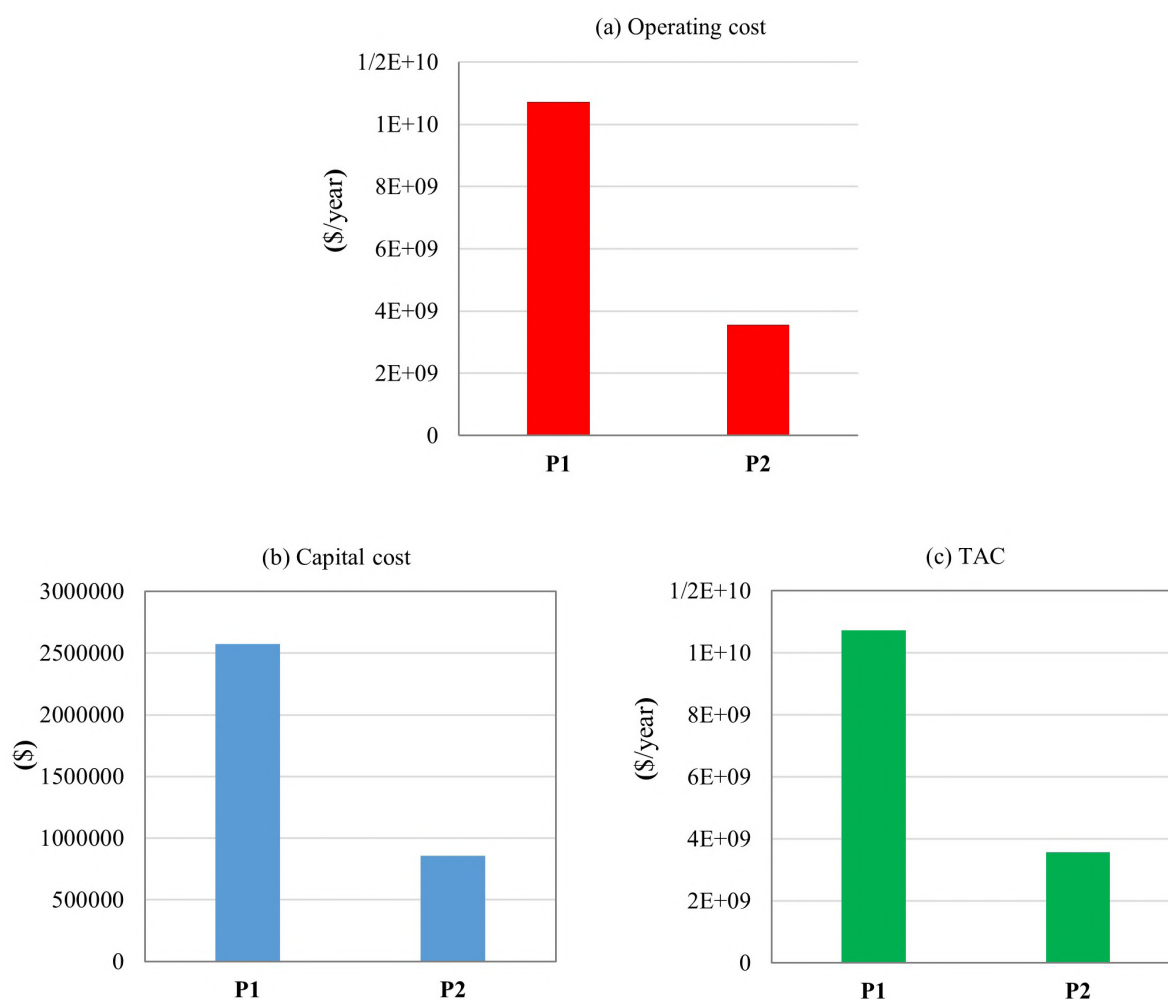


Figure 4. Comparison of Economic Costs (a) Operating Cost, (b) Capital Cost, (c) TAC

The natural gas sweetening unit is among the key units in any gas refinery complex. In this unit Hydrogen sulfide (H_2S) and carbon dioxide (CO_2) should be completely removed from the natural gas. A natural gas sweetening unit usually involves an absorption column

and a distillation column. monoethanolamine was used in this study to remove H_2S and CO_2 . The main problem is high energy consumption in the gas sweetening process so that large part of energy is consumed in the distillation column for amine recovery. Accordingly, energy

optimization of this process seems necessary given the global energy crisis in recent years. A novel method was used in this study for heat integration of the natural gas sweetening process. Two side streams from absorption column were used to supply the heat duty of the distillation column. A liquid stream enters the upper part of the distillation column from the lower part of the absorption column. A vapor stream leaves the upper part of the absorption column and enters the lower part of the distillation column. The presence of liquid and vapor in the distillation column reduces the heat duties of the reboiler and condenser. The feed entering the distillation column is preheated by its bottom product, reducing the heat duty of the reboiler. The bottom product of the distillation column containing amine is recycled to the absorption column after being pre-cooled by the sweet gas stream, significantly reducing the hot and cold utilities of the process. According to the results, the proposed method reduced the cold and hot utilities of the process by 67%. Significant reduction in energy consumption in the proposed process drastically reduces the amount of vapor and cold water consumed. It significantly reduces the operating costs and thus a significant reduction in TAC, as it concluded after TAC calculations for the two processes. Results indicated that the proposed process could decrease TAC of the base process about 66.77%.

Nomenclature

| | |
|-------------|-----------------------|
| <i>DEA</i> | diethanolamine |
| <i>DGA</i> | diglycolamine |
| <i>DME</i> | dimethoxyethane |
| <i>MDEA</i> | methyl diethanolamine |
| <i>MEA</i> | monoethanolamine |

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ارائه یک روش جدید در انتگراسیون حرارتی فرآیند شیرین سازی گاز طبیعی

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چکیده

واحد شیرین سازی گاز طبیعی عموماً دارای یک برج جذب و یک برج تقطیر است به طوری که از برج جذب برای حذف کامل گازهای CO_2 و H_2S از گاز طبیعی و از برج تقطیر برای بازیابی حلال استفاده می شود. مشکلی که وجود دارد این است که میزان انرژی مصرفی فرآیند شیرین سازی گاز به ویژه برج تقطیر آن بسیار بالا است. بنابراین بهینه سازی انرژی این فرآیند الزامی است. در این مقاله از یک روش جدید برای انتگراسیون حرارتی فرآیند شیرین سازی گاز طبیعی استفاده شده است. بدین منظور دو جریان مایع و بخار از برج جذب خارج شده و به ترتیب وارد بخش بالای برج و بخش پایین برج می شوند. همچنین خوراک ورودی به برج تقطیر به کمک محصول پایین برج پیش گرم می شود. حضور دو جریان مایع و بخار باعث کاهش مصرف یوتیلیتی سرد و گرم در برج تقطیر می شود و پیش گرم کردن خوراک نیز بار حرارتی ریبولر را کاهش می دهد. سپس حلال برگشتی به کمک گاز شیرین پیش سرد می شود. نتایج نشان می دهد روش پیشنهادی مقدار انرژی مصرفی فرآیند را به میزان ۶۷ درصد کاهش می دهد. علاوه بر این، فرآیند پیشنهادی می تواند هزینه کل سالیانه (TAC) را نسبت به فرآیند پایه به مقدار ۶۶٫۷ درصد کاهش دهد. این کاهش هزینه کل سالیانه (TAC) ناشی از کاهش هزینه عملیاتی و هزینه سرمایه گذاری به ترتیب به میزان ۶۶٫۷۷ و ۶۶٫۶۴ درصد است.

واژگان کلیدی: شیرین سازی گاز طبیعی، مونو اتانول آمین، انتگراسیون حرارتی، کاهش مصرف یوتیلیتی