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Comparison of Vapor Recompression and Bottom Flashing Methods in Energy Optimization of Natural Gas Sweetening Process

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ABSTRACT

The sweetening of sour gas by amine solvent has attracted a lot of attention due to the high ability of amines to remove acidic compounds from natural gas. In this process, an adsorption column and a distillation column are used to recover the amine. The operating costs of the conventional sour gas sweetening process are very high due to the high energy consumption in the solvent recovery column. Therefore, process energy optimization is very essential. In this research, first, the conventional gas sweetening process was subjected to heat integration (HI) so instead of using utility in supplying process energy, the energy of process flows has been used. Then, the amine recovery column is thermally integrated into this process by Vapor Recompression (VRC) and Bottom Flashing (BF) methods. The results showed that the HI, VRC, and BF processes reduced energy consumption compared to the conventional process about 25%, 88%, and 90%, respectively. Although the compressor consumption of the VRC and BF processes is almost the same, the reduction in hot and cold utility consumption in BF is 33% higher than in VRC. So, the BF process performs better than the VRC process. Moreover, BF process could reduce total annual cost (TAC) of the base process in the maximum value of 96%. That is why BF process is selected as the best choice of heat integration in this case study.

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1. Introduction

More than 40 percent of the world's natural gas reserves are sour, which contains significant amounts of sulfur and carbon dioxide. The percentage of natural gas reserves rises to 60 percent for the Middle East. Due to the contaminations of the environment caused by sour gas consumption, it is necessary to remove acidic compounds before use (Chen et al., 2021). The process of removing carbon dioxide and hydrogen sulfide compounds from sour gas is called gas sweetening (Abd et al., 2020). Until now various processes have been proposed for sweetening of natural gas, among which can be mentioned to adsorption processes by chemical solvents, physical solvents, and physical-chemical solvents. Using amines is the most common method of sour gas sweetening. Amines have a high ability to absorb acidic compounds of sour gas. Among amines, monoethanolamine (MEA) is a common solvent for the adsorption of carbon dioxide and hydrogen sulfide. MEA is the cheapest alkanoamine, so it has the highest theoretical capacity to absorb carbon dioxide (Aghel et al., 2020). In the sweetening operation of sour gas by amine, the gas flow and the liquid amine solution are contacted in an adsorption column. Normally, the gas to be sweetened enters the adsorption column from below, and the sweetened gas exits from the top of the adsorption column. The solvent also enters from the top of the adsorption column and exits from the bottom of the adsorption column. To reduce the viscosity of the circulating fluid, the circulating amine is diluted with water. The liquid amine solution containing the acidic compounds of the sour gas is transferred to a solvent recovery unit where the acidic compounds are removed from the amine (Long and Lee, 2017). The acid-free amine solution is removed from the bottom of the column, cooled, and returned to the adsorption column. Sweetening gas by using amine solvent is a process with high energy consumption, therefore, energy optimization in the amine plant becomes a concern for most operating companies (Song et al., 2017). In recent years, various methods have been proposed to reduce the energy consumption (Mix et al., 1981), such as HIDiC method, feed splitting method, external heat pump method, and so on (Díez et al., 2009). VRC and BF are the two methods that have been used in this study to reduce the energy consumption of distillation columns. In the VRC method, the output vapor from the top of the column is compressed by passing through the compressor, and pressure and temperature increase. Then the vapor releases heat, by exchanging heat in a heat exchanger, and heats the liquid flowing out from the bottom of the column (Cong et al., 2018). In the BF method, the flow pressure and temperature are reduced by passing the downflow of the column through the throttle valve. The cooling flow passes through the heat exchanger and heats up so receives heat from the outlet flow above the column (Díez et al., 2009; Jogwar and Daoutidis, 2009). Dai et al, to reduce the operating cost of the process of removing acidic compounds from natural gas, added two flash columns between the two columns of adsorption and distillation in the conventional process and successfully reduce energy consumption by 2.2 × 10^9 kJ/h (Dai et al., 2019). To reduce the energy consumption of the process of removing acidic gas compounds, Long and Lee used the heat pump arrangement and heat integration of several distillation columns and reduced the reboiler heat duty and operating cost by 62.5% and 45.9%, respectively (Long and Lee, 2017). Amri and Zahid presented an improved layout of the sweetening unit. In the proposed method, the energy consumption of the process was reduced by 22% due to the reduction of the amine circulation flow. The results showed that the proposed method has an 18% lower annual cost compared to the initial case(Al-Amri and Zahid, 2020).

This study aims to reduce the overall energy consumption of the natural gas sweetening process. First, the heat integration between the heater and the cooler used in this process is done to reduce the total energy consumption of the process (HI). Then the methods of heat integration of VRC and BF to reduce the total energy consumption of the solvent recovery column in the integrated thermal process of gas sweetening are investigated. In both VRC and BF methods, the need for hot and cold utility can be reduced by creating heat exchange between the adsorption and desorption sections. Therefore, in this paper, using these two methods, an attempt has been made to reduce the overall energy consumption of the solvent reduction distillation column. Of course, compressors must be used in both processes, and the output pressure of the compressor as the main variable in process energy optimization must be accurately calculated. All processes are accurately simulated and the total energy consumption and TAC for each process are calculated and compared.

2. Case Study

In this study, natural gas sweetening is performed by using monoethanolamine solvent. In the adsorption column, carbon dioxide and hydrogen sulfide are released from the gas, and sweet gas is released from the top of the adsorption column. In the second column, the solvent recovery operation is developed and the bottom product of the column with the specifications of the input solvent is returned to the first column. The feed conditions of the sour gas and the solvent are given in (Table 1).

Table 1. Information about the Sour Gas and the Solvent Feed

Process Characteristic		Sour Gas	Solvent (MEA)
Temperature (°C)		30	30
Pressure (kPa)		3000	5000
Molar flow (kmole/h)		3888	4377
Mole fraction	Methane	0.85	0
	Ethane	0.04	0
	Propane	0.02	0
	i-butane	0.007	0
	n-butane	0.006	0
	i-pentane	0.004	0
	n-pentane	0.003	0
	Carbon dioxide	0.03	0
	Hydrogen sulfide	0.02	0
	Nitrogen	0.01	0
	Water	0.01	0.8878
	Monoethanolamine	0	0.1122

3. Process Simulation

Aspen Hysys V.11 was used to simulate the processes. The Acid Gas-Chemical Solvents equation is used as the thermodynamic package. Also, instead of using shortcut methods, the Modified HYSIM Inside-Out solution method has been used rigorously to solve the columns.

3.1. Conventional Process

(Figure 1), shows the simulation of the conventional natural gas sweetening process by using amine solvent, in Aspen Hysys software.

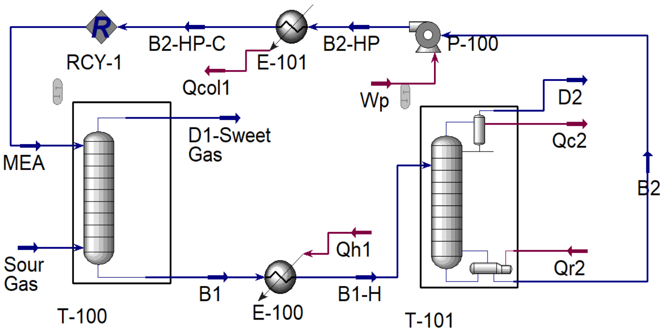

Figure 1. Conventional natural gas sweetening process in Aspen Hysys

In this process, both absorption and distillation columns have 20 trays. The bottom flow of the adsorption column, which contains solvent, hydrogen sulfide, and carbon dioxide, after heating enters the fifth tray of the second column to recover the solvent. The pressures at the top and bottom of the adsorption column are 4800 kPa and 4900 kPa, respectively. The pressures at the top and bottom of the distillation column are 101.3 kPa and 130 kPa, respectively. The top product of the first column is sweet gas. The bottom product of the second column, which is the solvent, is returned to the absorption column.

3.2. Heat Integration of the Process

By heat integration between inlet flow to the second column and bottom flow of the second column in a heat exchanger, the consumption of hot utility is eliminated and the amount of cold utility is reduced. The temperature of the second column downflow reached 83.86°C. To reduce the temperature of the flow to 30°C, a cooler is needed, which is also shown in (Figure 2).

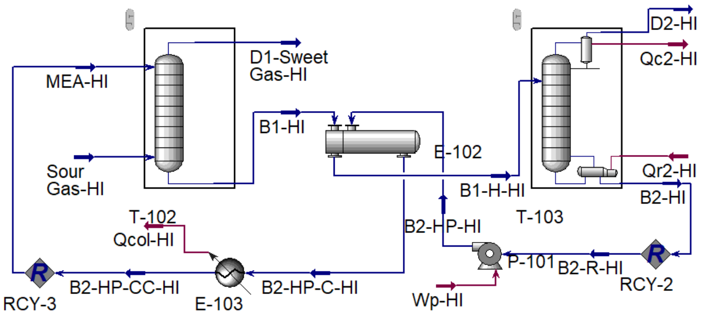

Figure 2. Heat integration simulation of the conventional natural gas sweetening process in Aspen Hysys

3.3. Vapor Recompression Method

(Figure 3), shows the simulated heat integration of VRC process in Aspen Hysys.

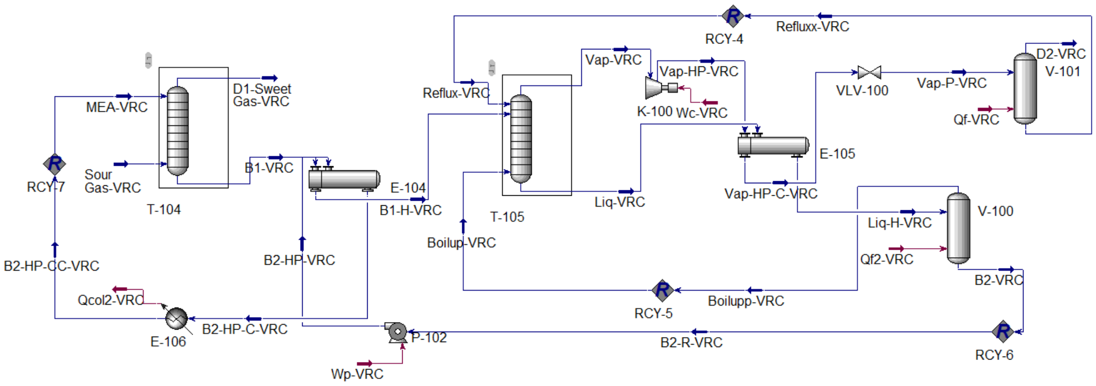

Figure 3. Simulation of the VRC heat integration process in Aspen Hysys

As shown in (Figure 3), the vapor at the top of the column is compressed by passing through the compressor to a pressure of 165 kPa. The minimum allowable temperature difference of the heat exchanger is 5 ˚C (ΔTappmin = 5). First, the cooled fluid output from the exchanger passes through the throttle valve. Then, reaches the product pressure above the column and enters the two-phase separator. The vapor flow is the top product and the liquid flow is as the second column's reflux. The heated fluid output from the heat exchanger also enters another two-phase separator, thus the liquid flow is the bottom product and the vapor flow is as the second column's boilup. The bottom product returns to the absorption column after increasing the pressure and decreasing the temperature to 30˚C in the cooler.

3.4. Bottom Flashing Method

(Figure 4), shows the BF method heat integration process simulation in Aspen Hysys.

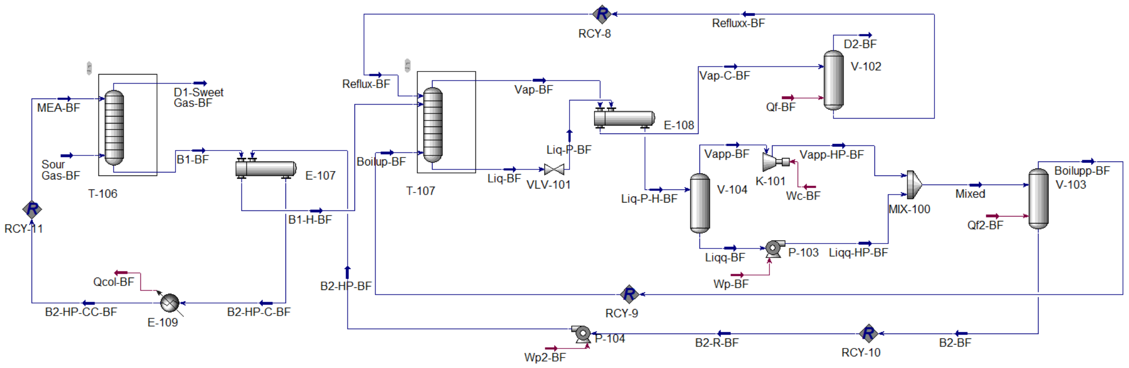

Figure 4. Simulation of BF heat integration process in Aspen Hysys

As shown in (Figure 4), the pressure of the outlet fluid from the bottom of the second column decreases to 77 kPa by passing through the throttle valve and receiving heat from the top vapor flow of the column in the heat exchanger. Pressure of the heated fluid increases and enters a separator and creates the bottom product and boilup. The cooled liquid leaving the exchanger enters a separator and creates top product and reflux.

4. Results and Discussion

In this article, 4 different processes for sweetening natural gas are examined. (Table 2), shows the energy consumption of each process.

Table 2. Energy Consumption in Different Processes

Process	Hot Utility(MW)	Cold Utility(MW)	Compressor Consumption (MW)
Conventional Process	65288.747	65293.053	---
Heat Integration Process	49070	49065.651	---
VRC Process	2691	5311.696	2354
BF Process	1429	3936	2545

The energy of a process is calculated by using eq. (1).

$$Q = Q_c + Q_r \qquad (1)$$

Where Q, Q_c, and Q_r indicate the process energy consumption, cold utility and hot utility, respectively.

But in VRC and BF methods, due to the compressor, the energy consumed is obtained from eq. (2).

$$Q' = Q_c + Q_r + 3Wcomp \qquad (2)$$

Where Q′, Q_c, Q_r and W_{comp} represent the process energy consumption, cold utility, hot utility and compressor consumption, respectively. Since compressor efficiency has been considered 33%, factor 3 is used to convert compressor electricity energy consumption to heat energy in this equation (Babaie and Esfahany, 2020).

(Figure 5), shows a comparison of energy consumption in the investigated processes.

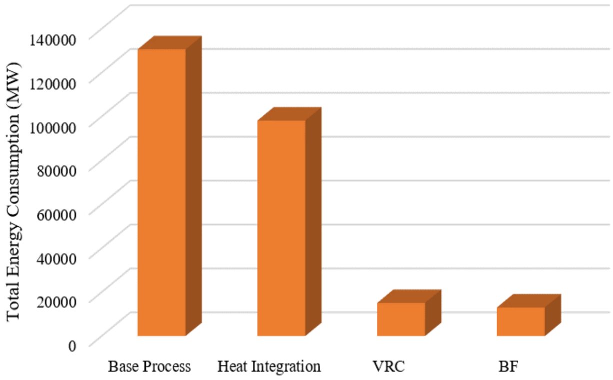

Figure 5. Comparison of energy consumption between different processes

According to (Figure 5), the BF method has the lowest amount of energy consumption and is therefore selected as the best process, the most important reason for this choice is to significantly reduce the need for hot and cold utilities.

Since in the studied heat integration processes, VRC and BF, as the best process in energy saving, the number of equipments are increased compared to the base process, TAC has been studied for all four processes and the results are compared. As it's clear from eq. (3), TAC is the summation of operating costs and annualized capital investments. In this equation, payback factor has been considered as five years to annualize the capital cost. Therefore, both operating and capital costs (C_{Op} and C_{Cap}) affect the amount of TAC. In eq. (4) & (5), it's determined which factors affect C_{Op} and C_{Cap}.

$$TAC = f(C_{Op}, C_{Cap}) = C_{Op} + \frac{C_{Cap}}{Payback\ Factor} \tag{3}$$

$$C_{Op} = f(C_{Utility}, T_{cond}, Q_{cond}, T_{reb}, Q_{reb}, C_{elect}) \tag{4}$$

$$C_{Cap} = f(P, H_{Col}, D_{Col}, A_{HX}, C_{pump}, C_{Compressor}) \tag{5}$$

Economic calculations are carried out based on the equations and costs for capital investment proposed by Sieder et al. (Seider et al., 2009). The considered cost index to correlate capital cost has been reported from chemical engineering plant cost index for 2022 (CE=622.5). Operating costs of columns were calculated by selecting the suitable utility types for reboilers and condensers according to their temperatures (Babaie and Esfahany, 2020). Furthermore, operating costs of compressor and pump were determined based on the cost of electricity (Li and Kiss, 2021).

The results of TAC calculations for the all considered processes indicate that, although BF process utilizes the most equipments of them, but it could reduce TAC of the base process in the maximum value. In (Table 3), number of each equipment is summarized for each process and in (Figure 6), the comparison of TAC reduction percentage compared to the base process is proposed for the three considered heat integration processes.

Table 3. Number of Different Equipments in the Processes

Process	Heat Exchanger	Distillation Column	Separator	Pump	Compressor
Base Process	4	2	0	1	0
HI	4	2	0	1	0
VRC	5	2	2	1	1
BF	5	2	3	2	1

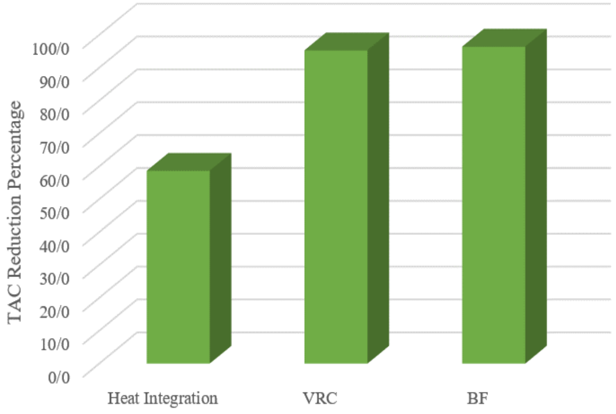

Figure 6. Comparison of TAC reduction percentage compared to the base process

5. Conclusion

In this study, the sweetening process of sour gas by using amine solvent is investigated. In this process, an absorption column is used to separate carbon dioxide and sulfur, and a distillation column is used to recover amine. The energy consumption of the sweetening process is high, so it is necessary to use energy optimization methods. VRC and BF have been used. Also, by using heat integration in VRC and BF methods, new processes with less energy consumptions were proposed. The results show that the three processes HI, VRC and BF have reduced total energy consumption about 25%, 88%, and 90%, respectively, compared to the conventional process. Significant reduction in energy consumption in all three methods drastically reduces the amount of vapor consumed and cold water consumed, which significantly reduces operating costs and thus a significant reduction in TAC, as it concluded after TAC calculations for the four processes. Results indicated that HI, VRC, and BF processes could decrease TAC of the base process about 56.8%, 95.3%, and 96.4% respectively Therefore, the BF method is selected as the best heat integration method in this study. The compressor consumption in VRC and BF process is the same. The consumption of hot utility and cold utility is reduced 47% and 26% in BF compared to VRC, which indicates better performance of the BF process than VRC.

Nomenclature

BF	bottom flashing
HI	heat integration
HIDiC	internally heat-integrated distillation column
MEA	monoethanolamine
TAC	total annual cost
VRC	vapor recompression

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مقایسه دو روش تراکم بخار و تبخیر ناگهانی محصول پایین در بهینه‌سازی انرژی فرآیند شیرین‌سازی گاز طبیعی

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چکیده

شیرین‌سازی گاز ترش به کمک حلال آمین به دلیل توانایی بالای آمین‌ها در حذف ترکیبات اسیدی از گاز طبیعی، همواره موردتوجه بوده است. در این فرآیند از یک برج جذب و یک برج تقطیر به‌منظور بازیابی آمین استفاده می‌شود. به دلیل مصرف انرژی بالا در برج بازیابی حلال، هزینه‌های عملیاتی فرایند متداول شیرین‌سازی گاز ترش بسیار بالا است. از این رو بهینه‌سازی انرژی فرآیند یک امر ضروری محسوب می‌شود. در این پژوهش ابتدا فرآیند مرسوم شیرین‌سازی گاز مورد انتگراسیون حرارتی (HI) قرار گرفته است به نحوی که به جای استفاده از یوتیلیتی در تأمین انرژی فرآیند، از انرژی جریان‌های فرآیندی استفاده شده است. سپس برج بازیابی آمین در این فرآیند با استفاده از روش‌های تراکم بخار (VRC) و تبخیر ناگهانی محصول پایین (BF) یکپارچه حرارتی شده است. نتایج نشان می‌دهد که سه فرآیند HI، VRC و BF نسبت به فرایند مرسوم به ترتیب حدوداً ۲۵درصد، ۸۸ درصد و ۹۰ درصد کاهش مصرف انرژی داشته است. با وجود اینکه کار مصرفی کمپرسور در دو فرآیند VRC و BF تقریباً یکسان است، اما کاهش مصرف یوتیلیتی سرد و گرم در فرآیند BF نسبت به VRC ۳۳ درصد بیشتر بوده است. بنابراین، فرآیند BF عملکرد بهتری را نسبت به فرآیند VRC دارد. علاوه بر آن، فرآیند BF هزینه کلی سالیانه فرآیند مرسوم را در بیشترین مقدار به میزان ۶۹ درصد کاهش می‌دهد. به همین علت فرآیند BF به عنوان بهترین انتخاب انتگراسیون حرارتی برای این مطالعه موردی انتخاب شده است.

واژگان کلیدی: شیرین‌سازی گاز ترش، انتگراسیون حرارتی، تراکم بخار، تبخیر ناگهانی محصول پایین