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Using the Feed Splitting Technique in Optimizing the Energy for the Natural Gas Sweetening Unit of the Ilam Gas Refinery

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ABSTRACT

The sweetening unit of the Ilam Gas Refinery plays a major role in providing olefin feed, and at the present time, the provinces of Ilam, Kermanshah, Hamedan, Kurdistan, and Lorestan in Iran are the consumers of the gas produced by this refinery. The gas sweetening unit of the Ilam Gas Refinery has an absorption and distillation column. H2S and CO2 are removed by diethanolamine in the absorption column, and the entrainer is recovered in the distillation column. The concern is the high energy consumption of this process, particularly the distillation column. In this study, a novel method for heat integration of the distillation column of the gas sweetening unit of the Ilam Gas Refinery was used, so that the feed entering the distillation column was splitted into two sections prior to feeding. Afterwards, the bottom section was preheated by the bottom product of column. Preheating the bottom section of feed decreased the reboiler and condenser duties. The results demonstrate that the proposed method decreases the energy consumption by 17%.

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1. Introduction

Given the eco-friendly policies and H_2S toxicity, the process of gas sweetening is essential to remove H_2S and CO_2 from the refinery gas (Zhu et al., 2021a). Different techniques have been used to remove acidic components from natural gas, such as absorption through physical solvents, chemical solvents, mixed solvents, adsorption, cryogenic separation and low temperature separation(Han and Ho, 2019; Jiang et al., 2019; Kheirinik et al., 2018; Langè et al., 2015; Rezakazemi et al., 2018). Among these, absorption through Alkanolamine solvents is widely used in numerous applications. Amines, also known as reducing solvents, are extensively employed in sweetening of natural gas. Such solvents have some advantages, such as low vapor pressure and energy consumptions as well as high capacity and consistency. The conventional natural gas sweetening solvents usually involve Monoethanolamine (MEA), diethanolamine (DEA), and methyl diethanolamine (MDEA) (Abd and Naji, 2020; Jamekhorshid et al., 2021). A variety of studies have been conducted on natural gas sweetening.

Song et al. used MEA solvent and heat pump to improve the energy savings of natural gas sweetening process. In their paper, the extera condensate heat was saved via vapor recompression and the excess pressure was saved simultaneously by the expander. The total energy needed for the absorption process could be decreased to 7.2 megawattes, and the waste heat and pressure could be recovered by 38.1 MW. In comparison with the normal process, 33.4 MW of excess heat could be recovered (Song et al., 2017). Additionally, the energy consumed by the proposed method might decreased to 1.78 MJ to remove 1 kg of CO_2. Park et al. analysed the low temperature process known as LT based on the distillation process to enhance the energy efficiency in the sweetening process and CO_2 removal in large scale. Every one of the simulations were conducted by Aspen Hysys, which evaluated the sensitivity of key coefficients under different operating circumstances. The results showed that the best design and operating conditions were achieved at a pressure of 4254 kpa and lateral flow ratio of 0.55 at 40 trays. The findings of operating cost for the LT process estimated 15.22 thousand dollars per hour.A new separator and a turbo expander were also proposed as modifications to the process. This new design increased the vapor fraction and recovered a greater power in the turbo expander. The operating pressure of the distillation column could be enhanced through such changes in operating conditions, reducing the existing carbon dioxide in the remaining gas and the flow of carbon dioxide entering the amine process. Compared to the initial state, the new configuration lowered the energy cost of the process by around 5% (Park et al., 2021). Hosseini et al. proposed an optimization approach for increasing CO_2 absorption as well as reducing energy consumption. Two objective functions of CO_2 absorption and energy recovery were defined and developed by the variables affecting the process. This optimization was carried out using a genetic algorithm and Aspen Hysys. The results demonstrated that the energy consumption for absorbing 94% of CO_2 using MDEA/PZ mixed solvents was much lower than the energy consumption for absorbing 90% of CO_2 from MEA solvent (Hosseini-Ardali et al., 2020). Zhu et al. suggested the pre-allocation method of sour gases accompanied by multi-feeding operation to optimize the distribution of temperature and concentration. The results of this method indicated that energy consumption and exergy loss were decreased by 6.5% and 16.5%, and the total economic profit was increased by 66.56% compared to the conventional natural gas sweetening (Zhu et al., 2021b).

Ilam Gas Refinery was built to supply the gas consumed in Ilam province and the western provinces of Iran, and also to provide the petrochemical feedstock for Ilam Petrochemical Co. and boost the gas pressure in western Iran. This refinery was initially launched at the autumn season of 2007 to purify the gas at the Tang-e-bijar gas field. This refinery was designed and constructed in two phases. The feed of the Ilam Gas Refinery was mainly supplied by the sour gases of the Tang-e-bijar gas field, entering the first phase of Ilam Gas Refinery through a pipeline at the capacity of 6.8 million m3 per day, and reaches 10.2 million m3 per day by adding a capacity of 3.4 million m3 in the final phase.

This paper aims to optimize the energy of the natural gas sweetening unit of the Ilam Gas Refinery. Hence, a new method was used for heat integration of the distillation column of the sweetening unit. In this technique, first the feed to the distillation column was splitted into two sections. Afterwards, the bottom sections of feed were preheated by the bottom products of the column. This decreased the reboiler and condenser duties. Feed splitting fraction and preheating rate of the bottom section of feed were the main variables of this technique that shall be calculated precisely.

2. Case Study

In this research, the gas sweetening of the Ilam Gas Refinery was studied. The conditions of feed and solvent used are presented in (Table 1).

Table 1. Feed/Solvent Conditions

Process Characteristic		Sour Gas	Solvent
Temperature [°C]		33.6	50
Pressure [kPa]		7600	7590
Molar flow rate [kgmol/h]		6144	8438
Mole fraction	Methane	0.8324	
	Ethane	0.0551	
	Propane	0.0230	
	i-Butane	0.0044	
	n-Butane	0.0062	
	i-Pentane	0.0021	
	n-Pentane	0.0021	
	n-Hexane	0.0013	
	n-Heptane	0.0006	
	n-Octane	0.0010	
	N_2	0.0013	
	CO_2	0.0374	
	H_2S	0.0325	
	H_2O	0	
	MDEAmine	0	
	DiM-Sulphide	0.0001	0.8976
	E-Mercaptane	0.0003	0.1024
	M-Mercaptane	0.0001	
	COS	0	

The gases produced from the oil reserves or in the gas industries contain various amounts of impurities. The presence of impurities in the industrial gases causes damage to the equipment and decreases the quality of industrial gases. The leakage of impurities into the environment will also cause contamination. In such cases, the impurities of gas flow are needed to be eliminated. Acidic gases, including carbon dioxide, hydrogen sulfide, and sulfur dioxide, are one of the most important impurities of gas flow. Absorbing acid gases is a critical process in many chemical industries, such as gas sweetening.

3. Process Simulation

Aspen Hysys V.10 was used to simulate the processes.The fugacity of the liquid and vapor phases was calculated by Acid gas-chemical solvent fluid package. Modified HYSIM Inside-Out was also the solving method for distillation columns.

3.1. Conventional gas sweetening process of the Ilam Gas Refinery

(Figure 1) represents the simulation of the conventional gas sweetening process of the Ilam Gas Refinery in Aspen Hysys. The feed stream entered the flash column for initial separation and then the sour gas and diethanolamine entered the bottom and top sections of the absorption column as the amine solvents, respectively. The absorption column had 20 trays and its high and low pressures were equal to 7580 kPa and 7600 kPa, respectively. The distillate product (sweet gas) and the bottom product were removed from the absorption column at a molar flow of 5784 kmol/h and 8798 kmol/h, respectively. After preheating, the downstream of the absorption column entered the 20-tray distillation column to purify the amines. The distillation column trays are considered ideal. The high and low pressures of the distillation column were 69 kPa and 110 kPa, respectively. The purified amine discharged from the distillation column returned to the first column.

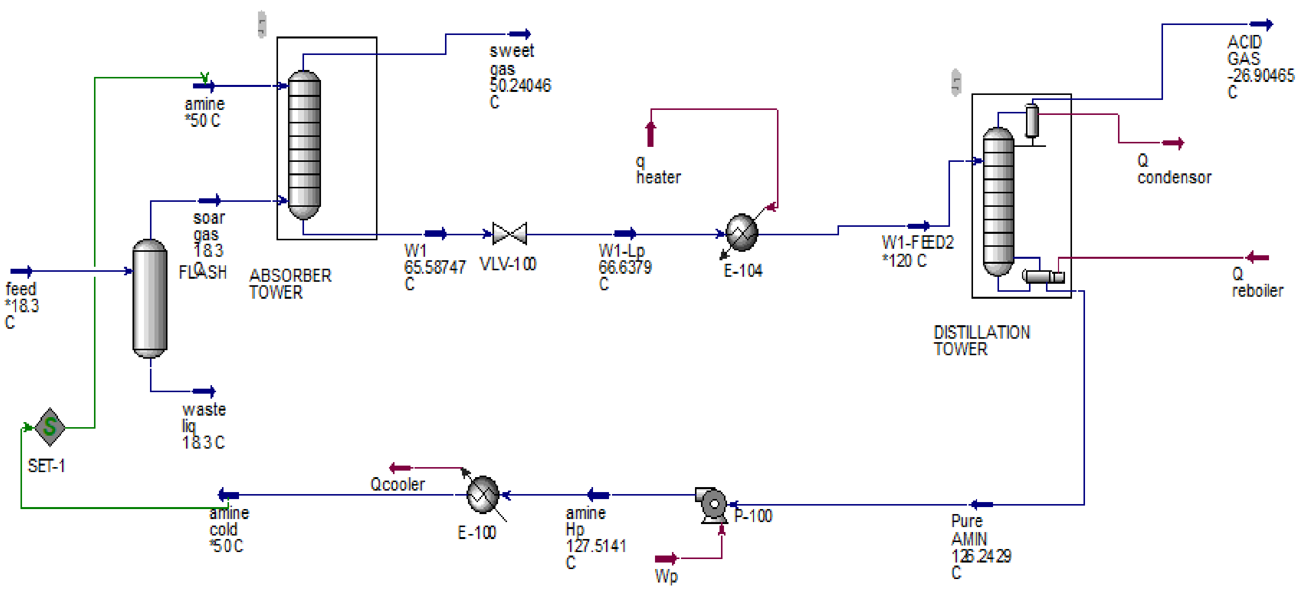

Figure 1. Simulation of the Conventional Gas Sweetening Process of the Ilam Gas Refinery in Aspen Hysys

Table 2. Conventional Process Characteristic

Process Characteristic	Sweet gas	RA	LP-RA	Hot -RA	Acid Gas	LA 2	LA-Cold	Make up	LA3	LA-HP
Temperature [°C]	50.62	62.93	63.87	80	40	102.9	86.33	82.59	86.32	87.53
Pressure [kPa]	7580	7600	380	360	69	110	90	90	90	7590
Molar flow rate [kgmol/h]	5784	8798	8798	8798	396.3	8402	8402	26	8428	8428
Mole fraction										
Methane	0.8819	0.0015	0.0015	0.0015	0.0343	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0584	0.0001	0.0001	0.0001	0.0033	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0244	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000
i-Butane	0.0046	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
n-Butane	0.0065	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
i-Pentane	0.0021	0.0001	0.0001	0.0001	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000
n-Pentane	0.0022	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
n-hexane	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Heptane	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Octane	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0020	0.8596	0.8596	0.8596	0.1077	0.8950	0.8950	0.8962	0.8950	0.8950
Nitrogen	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2S	0.0000	0.0227	0.0227	0.0227	0.4931	0.0005	0.0005	0.0000	0.0005	0.0005
CO_2	0.0130	0.0176	0.0176	0.0176	0.3572	0.0015	0.00015	0.0011	0.0015	0.0015
MDEA	0.0000	0.0982	0.0982	0.0982	0.0000	0.1028	0.1028	0.1027	0.1028	0.1028
DiM-Sulphide	0.0000	0.0001	0.0001	0.0001	0.0004	0.0001	0.0001	0.0001	0.0001	0.0001
E-Mercaptane	0.0003	0.0000	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000
M-Mercaptane	0.0001	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

3.2. Feed splitting technique

Given the high energy consumption of this process, an energy-saving technique is necessary. Feed splitting is a well-known method for Heat integration of distillation columns, was used due to its significant reduction of reboiler and condenser thermal load.

The amine-rich product discharged from the bottom of the distillation column entered the preheating heat exchanger to heat the remaining feed stream entering the column up to the temperature of 90 °C. The purified amine re-entered the absorption column after enhancing pressure and decreasing temperature. The preheated stream entered the sixth tray of the distillation column. The distillation column trays are considered ideal. It is worth mentioning that the pressure drop of the shell and tube side of both exchangers was considered 10 kpa. Thus, the heat flow of the reboiler and condenser was reduced after preheating the feed entering the distillation column.

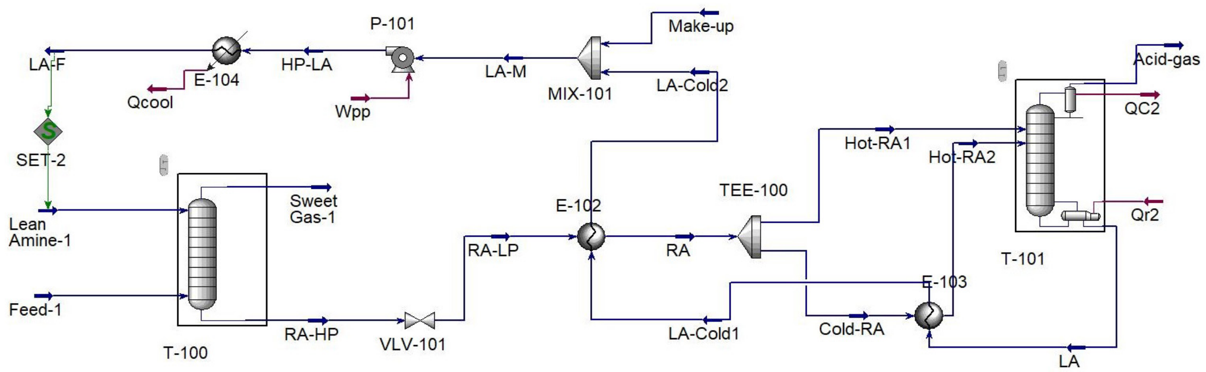

Figure 2. Simulation of Gas Sweetening Process with Feed Splitting Technique

Table 3. Feed Splitting Process Characteristic

Process Characteristic	Sweet Gas	RA-HP	RA-LP	RA	Cold-RA	Hot-RA1	Hot-RA2
Temperature [°C]	50.65	62.98	63.92	77	77	77	90
Pressure [kPa]	7580	7600	380	370	370	370	360
Molar flow rate [kgmol/h]	5784	8798	8798	8798	6159	2639	6159
Mole fraction							
Methane	0.8819	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Ethane	0.0584	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Propane	0.0244	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
i-Butane	0.0046	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Butane	0.0065	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
i-Pentane	0.0021	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
n-Pentane	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-hexane	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Heptane	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Octane	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.0020	0.8596	0.8596	0.8596	0.8596	0.8596	0.8596
Nitrogen	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2S	0.0000	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227
CO_2	0.0130	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176
MDEA	0.0000	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982
DiM-Sulphide	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
E-Mercaptane	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
M-Mercaptane	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Process Characteristic	**Acid-Gas**	**LA**	**LA-Cold1**	**LA-Cold2**	**Make-up**	**LA-M**	**HP-LA**
Temperature [°C]	39.98	102.8	92.1	78.6	82.59	78.61	79.79
Pressure [kPa]	69	110	100	90	90	90	7590
Molar flow rate [kgmol/h]	396.7	8401	8401	8401	26	8427	8427
Mole fraction							
Methane	0.0342	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0033	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
i-Butane	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Butane	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
i-Pentane	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Pentane	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Hexane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Heptane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n-Octane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2O	0.1077	0.8951	0.8951	0.8951	0.8951	0.8951	0.8951
N_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H_2S	0.4964	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
CO_2	0.3541	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
MDEA	0.0000	0.1028	0.1028	0.1028	0.1028	0.1028	0.1028
DiM-Sulphide	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
E-Mercaptane	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
M-Mercaptane	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

4. Results and discussion

This study investigated the sweetening of gas at the Ilam Gas Refinery using diethanolamine. The process was simulated by 2 methods with and without heat integration and (Figure 3) shows the energy consumption in each method. The quantity of energy consumed for the distillation column is calculated by the following equation (1):

$$Q_D = Q_C + Q_H \quad (1)$$

Where Q_D , Q_C , and Q_H represent the energy consumption of the distillation column, cold utility, and hot utility consumed for distillation column. The amount of total hot and cold utility is equal to:

$$Q_{hot\ utility} = Q_h + Q_{heater} \quad (2)$$

$$Q_{cold\ utility} = Q_C + Q_{cooler} \quad (3)$$

(Figure 3) shows a comparison between energy consumption in both processes:

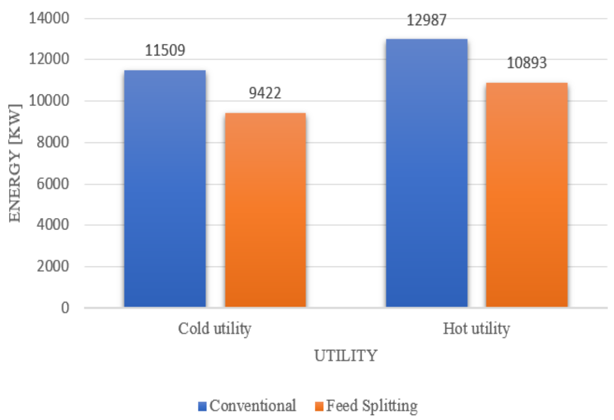

Figure 3. Comparison of Energy Consumption in Two Processes

The results show that the suggested method consumes lower energy than the traditional method, and therefore, the developed method is considered appropriate. The cooler has a thermal load of 2868 KW in the conventional process and 2611 KW in the feed splitting process. Moreover, in both processes, the pump power consumption is 655 KW.

5. Conclusions

The feed of the Ilam Gas Refinery was mainly supplied by the sour gases of the Tang-e-bijar gas field and injected into gas transmission pipelines after sweetening. The problem is the high energy consumption of the solvent recovery column at the natural gas sweetening unit of the Ilam Gas Refinery. Hence, the energy optimization is a necessity. In this paper, feed splitting was used for heat integration of this process. Compared to other heat integration methods such as vapor recompression and heat pump, feed splitting has the advantage of not requiring additional equipment, like compressors. In the proposed technique, the feed entering the distillation column was splitted into two sections. The bottom section of the feed was preheated by the bottom product to reduce the reboiler and condeser duties Accordingly, the proposed method reduced the energy consumption by 17%.

Nomenclature

DEA	Diethanolamine
LT	Low temperature
MDEA	Mmethyl diethanolamine
MEA	Monoethanolamine
PZ	Piperazine

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استفاده از روش شکستن خوراک در بهینه‌سازی انرژی واحد شیرین‌سازی گاز طبیعی پالایشگاه ایلام

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چکیـــــده

واحد شیرین‌سازی پالایشگاه گاز ایلام نقش اصلی در تأمین خوراک الفین دارد و در حال حاضر استان‌های ایلام، کرمانشاه، بخش‌هایی از همدان، کردستان و لرستان مصرف‌کننده‌ی گاز تولیدی این پالایشگاه هستند. واحد شیرین‌سازی گاز پالایشگاه ایلام دارای یک برج جذب و یک برج تقطیر است. در برج جذب به کمک حلال دی اتانول آمین، H_2S و CO_2 از گاز طبیعی حذف می‌شوند و در برج تقطیر نیز حلال استفاده شده، بازیابی می‌شود. مشکلی که وجود دارد این است که مصرف انرژی این فرآیند به‌ویژه برج تقطیر، بسیار بالا است. در این مقاله از روش Feed Splitting برای انتگراسیون حرارتی برج تقطیر واحد شیرین‌سازی گاز پالایشگاه ایلام استفاده شده است. به این صورت که خوراک ورودی به برج تقطیر قبل از ورود به برج به دو قسمت تقسیم می‌شود. سپس بخش پایینی آن به کمک محصول پایین برج پیش گرم می‌شود. پیش گرم کردن بخش پایینی خوراک باعث کاهش Heat Duty ریبویلر و کندانسور می‌شود. نتایج نشان می‌دهد که روش پیشنهادی میزان مصرف انرژی را ۱۷ درصد کاهش می‌دهد.

واژگان کلیدی: شیرین‌سازی گاز، دی‌اتانول آمین، پالایشگاه ایلام، تقسیم خوراک