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The Study of Decrease in CO_2 Emission using Pinch Technology

Mehdi Mohammadi Rahaghi[1], Majid Hayati-Ashtiani[2]✉

[1] Department of Chemical Engineering, Faculty of Engineering, University of Kashan, Iran. E-mail: mehdi.rahaghi@gmail.com
[2] Corresponding Author, Department of Chemical Engineering, Faculty of Engineering, University of Kashan, Iran.
E-mail: hayati@kashanu.ac.ir

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ABSTRACT

Naphtha hydrotreating is a refining process that removes sulfur, nitrogen, and other impurities from naphtha. CO_2 Emission Pinch Analysis (CEPA) is a technique used for planning and optimizing energy systems to minimize CO_2 emissions. This study aims to optimize the heat exchanger network of a naphtha hydrotreating unit based on the pinch technology with three designed scenarios to reduce the CO_2 emissions. In the scenario I the Heat Exchanger Network (HEN) is modified to achieve the optimum $\Delta T_{min.}$ using Pinch Technology. Fuel switching between natural and fuel gas is applied in scenario II for CO_2 emissions reduction. An economizer installation at the furnace stack is suggested in Scenario III to increase the thermal efficiency of the furnaces and reduce CO_2 emissions. Ultimately, the integration of all three scenarios is effectively performed. Scenario I reduces the energy consumption of hot utilities and CO_2 emissions by 40.4% and 41.3%, respectively. The total annual cost of the unit is minimized in scenario I at the optimum $\Delta T_{min.}=12^{\circ}C$. Scenario II reduces the fuel consumption from 100 kg/h and the CO2 emission by 16%. While scenario III decreases CO_2 emission by 5.5%, the new integration method of scenarios I–III provides the minimum emission reduction by 52.3%. The use of natural gas instead of fuel gas, and energy recovery from flue gas to preheat the incoming streams to the furnace in scenarios II and III are found to be the reasons for the efficient CO_2 emission reduction of the hydrotreating unit.

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1. Introduction

Naphtha hydrotreating is a petroleum refinery unit that de-sulfurizes and de-nitrogenizes light naphtha, allowing for the achievement of high octane number gasoline objectives. In this unit, destructive environmental elements such as sulfur, nitrogen, oxygen, and heavy metals are effectively removed using hydrogen in the hydrotreating process. The process feed is mixed with hydrogen gas as its temperature increases, until it reaches full evaporation. Then, the resulting flow enters the catalytic reactor to completely remove some elements such as sulfur, nitrogen, and oxygen in the form of H_2O, H_2S, and NH_3 released from the reactor. With its two furnaces, this unit is considered one of the most energy-consuming and polluting units. Process heat integration and modification of furnaces along with reducing fuel and energy consumption lead to reducing CO_2 emissions.

Graphical methods resolve the supply–demand matching problems in the processes of heat transfer using graphical analysis theory [1]. Pinch Analysis was first developed for the optimal design of heat exchange networks by Hohmann and further developed by Linnhoff and Flower [2]. Energy analysis is integrated with exergy analysis in order to provide a more accurate evaluation [3-4]. CEPA is a methodology used for energy planning that incorporates carbon emission constraints. It is an extension of traditional pinch analysis techniques, adapted to consider CO_2 emissions as a limiting factor in energy system design. CEPA helps identify optimal strategies for energy allocation, taking into account both energy demand and carbon emission targets [5]. Tan and Foo [6] introduced a tool for early planning of CO_2 emissions in the electricity sector in the carbon pinch analysis. They presented a graphical method to pinch the amount of CO_2 emissions in different regions with the type of fuel consumed, and as a result, CO_2 emissions were reduced by 15%. The use of graphical, numerical, and other methods to reduce CO_2 emissions has been the technics in recent years [7-8]. The new design of the HEN (Heat Exchanger Network) was done with $\Delta T_{min.}$=2.5 in Kero hydrotreating unit [9]. We considered the optimal $\Delta T_{min.}$ in our study. In thas project, the CO_2 emissions were reduced by 34%. However, economic considerations have not been made to determine the $\Delta T_{min.}$ in this design. Researchers investigated different ways of using utility services and reducing CO_2 emissions. They used the lowest total annual costs of crude oil pre -heat train as the basis for determining the optimal $\Delta T_{min.}$ [10]. Mrayed et al. [11] managed to achieve a 30% reduction in CO_2 emissions in the crude oil distillation unit by presenting a new network of heat exchangers using pinch technology. Li et al. [12] determined the optimal $\Delta T_{min.}$ by considering the total annual costs of the unit as well as the carbon emission tax. Through changing the $\Delta T_{min.}$ from 9 to 8°C, they managed to reduce 4.42% in carbon emissions. Compared to the base-case, they reduced the CO_2 emission by 48%. Diamante et al. [13] applied pinch technology-based methodology examining every sink as well as time of carbon capture and storage. They studied three cases to show the application of their suggested methodology. Two cases demonstrated graphical and algebraic alternatives, and the third showed an extension. Zhelev and Semkov [14] showed the temperature of flue gas could be decreased by designing economizer systems using pinch analysis. Their results showed their designed systems are more suitable for industrial applications.

The researchers proposed using the pinch technology to decrease CO_2 emission and reduce the overall energy consumption of the Light Naphtha Isomerization unit using Aspen Energy Analyzer V10 [15] but the CO_2 emission is not studied in Light Naphtha Hydrotreating unit. We studied this unit, too. The results showed the elimination of $2.85\times10^{+7}$ kg CO_2/year. Carbon emissions also pose a formidable challenge for fossil fuels. Researchers suggested specific emission reduction strategies. Carbon-neutral energy sources, encompassing solar, wind, hydroelectricity, biomass, and nuclear, are estimated to cover 56.06% of energy demand by 2040, driving a 33.30% emissions reduction [16]. Carbon Emission Pinch Analysis (CEPA) can also be applied in Local power plants. In a study, some plants were screened, and a carbon capture and storage retrofit was then technically designed using Aspen HYSYS.

Multi-period CEPA methodology was then applied to quantify 17% of grid energy from renewable energy along with CCS to achieve the emission reduction target [17].

This research aims to study the methods of CO_2 emissions reduction by reducing the amount of energy consumption and process optimizations in a Hydrotreating unit produces gasoline, which creates waste heat and pollution. Case data of a real factory's heat exchanger network was studied. In addition to retrofitting the HEN to achieve the minimum optimum temperature difference and three network optimizations, furnace fuel switching is investigated. Studying the new method to use the waste heat in furnaces resulted in new retrofit designs using Economizer to decrease pollution and boost energy efficiency. The other innovation is the integration of three optimization methods to achieve the highest amount of CO_2 emissions reduction. Therefore, the CO_2 emission decreased to 1386 kg/h compared to the base-case.

2. Concepts and methodology

2.1. Process description

The light naphtha hydrotreating unit was selected as a case study in this research. The unit feed is the light naphtha stream from the atmospheric distillation column and the harmful compounds containing sulfur and nitrogen are completely removed from the naphtha fed in this unit. Then, the hydro treated naphtha is sent to the isomerization unit for the production of high-quality gasoline.

Fig. 1 shows the process flow diagram of the light naphtha hydrotreating unit. In this process, the feed stream is combined well with the hydrogen-rich flow to be preheated in the heat exchanger E-1801. The combined flow enters the catalytic reactor after reaching the reactor inlet temperature in furnace H-1801. The harmful compounds are then removed from the reactor feed in the form of H_2S and NH_3. The reactor effluent is cooled in heat exchangers and enters V-1802 where the hydrogen-rich gas is removed.

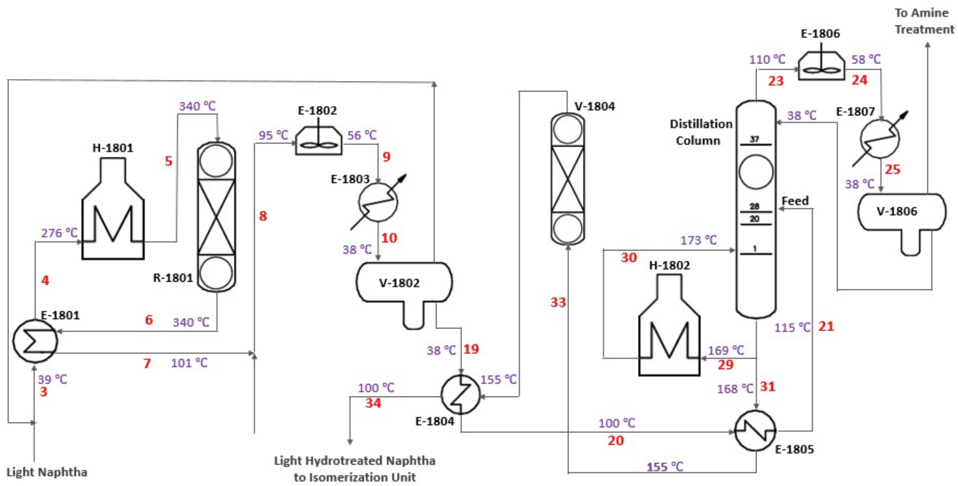

Fig. 1. Process flow diagram of light naphtha hydrotreating unit

The remaining liquid stream flows to the distillation column and the light compounds and H_2S are fully removed from the column feed. The purified naphtha from the bottom of the column is then sent to the isomerization unit. Furnace H-1802 plays the role of distillation column reboiler. Two furnaces, H-1801 and H-1802, play the role of hot utility service provider in the unit. These furnaces are natural draft type using fuel gas as fuel. As a result of the combustion process, a significant amount of carbon dioxide and heat is released from the furnace stack into the atmosphere and a small amount of other greenhouse gases are emitted along with CO_2.

2.2. Problem statement

Considering the relatively high emission of greenhouse gases in the unit furnaces, the main goal of this research is to reduce both CO_2 emissions and energy consumption in utility services. The lack of optimal design of the heat exchanger network and inappropriate operating conditions in the distillation column and furnaces lead to extra thermal load to the utility services and excessive CO_2 emissions.

Fortunately, in response to the existing problems, our research provides several solutions to improve the current situation. In this research, some solutions have been presented to solve CO_2 emissions and energy consumption problems largely including modifying the heat exchanger network with an economic approach, changing the operational conditions in distillation column and furnaces, and changing the type of fuel consumed.

2.3. CO_2 emission calculations

The amount of carbon dioxide emission, $[CO_2]_{Emission}$ (kg/s), to the environment is calculated using Eqs. (1)-(3) [18]:

$$(CO_2)_{Emission} = \left(\frac{Q_{Fuel}}{NHV}\right) \times \left(\frac{C\%}{100}\right) \times \alpha \tag{1}$$

$$Q_{Fuel} = \frac{Q_{Process}}{\varphi_{Furnace}} \tag{2}$$

$$\varphi_{Furnace} = \frac{T_{TFT} - T_{Stack}}{T_{TFT} - T_O} \tag{3}$$

Where, Q_{Fuel} is the heat load released by the consumed fuel (kW), $Q_{Process}$ heat load used in the process or thermal equipment (kW), $\varphi_{Furnace}$ thermal efficiency of the furnace, T_{TFT} theoretical flame temperature (°C), T_{Stack} temperature of the exhaust gas from the furnace stack (°C), T_o temperature of the surrounding environment (°C), NHV (Net Heat Value) of the fuel used in the furnace (kJ/kg), C% percentage of carbon in the fuel used and α(=3.67) is the molar mass ratio for CO_2 to C which is a constant coefficient. 15-20% excess air was applied for complete combustion [19].

The heat recovered ($\dot{Q}$) from the Flue gas (kW) is calculated using Eq. (4) as follows:

$$\dot{Q} = \dot{m} C_p (T_{Stack} - T_{Process\ Inlet}) \tag{4}$$

Where $\dot{m}$ and C_p are the Flue gas flow rate (kg/s) and the heat capacity of the outlet Flue gas (kW/kg.°C), respectively.

3. Results and discussion

Three scenarios that are more possible have been well studied in detail to optimize energy consumption and CO_2 emission reduction in the Naphtha Hydrotreating Unit (NHU). The results of the possible scenarios have been carefully evaluated and compared in energy consumption, CO_2 emission, and economic costs. Finally, the authors attempted to obtain the best scenario by integrating the scenarios. The three suggested scenarios are as follows:

Scenario I: Modifying the HEN to achieve the minimum optimum temperature difference between the cold and hot streams to reduce the subsequent CO_2 emissions (MER (Minimum Energy Requirement or Maximum Energy Recovery) Design).

Scenario II: Investigating replacing the type of consumed fuel in furnaces so as study the thermal load and CO_2 emissions reduction (Fuel Switching).

Scenario III: Installing an economizer at the furnaces stack to increase the thermal efficiency of the furnaces to reduce fuel consumption and CO_2 emission (Economizer Design).

Combination of scenarios: the combination of scenarios I-III can be as one of the options and compared together.

3.1. Base-case studies

The NHU mainly consists of a reactor, a distillation column, two furnaces, seven heat exchangers, several vessels and pumps. The two furnaces provide the hot utilities. The natural draft furnaces use Fuel Gas. The fuel consumption rates in H-1801 & H-1802 furnaces are 400 kg/h and 550 kg/h. The heat loads of the furnaces are 4.4 MW and 6.09 MW, respectively. Generally, 10.49 MW of the hot utilities is supplied by furnaces. The heat is transferred from burner to streams in furnaces only in the Radiation and Convection sections and there is no heat transfer in the furnace stack (Economizer section). Air and water coolers provide the cold utilities. The total hot and cold utility loads of the base-case design are 10.49 and 7.33 MW, respectively. The data of the hot and cold streams and heat exchangers are given in Table 1.

Table 1. Specification of streams and heat exchanger of the unit

No.	HX name	Stream No.	Stream name	Supply temperature (°C)	Outlet temperature (°C)	Heat load (MW)
1	E-1801 (A,B,C,D,E)	3-4	Reactor Inlet	39	276	19.89
2	H-1801	4-5	Reactor Inlet	276	340	4.40
3	E-1801 (A,B,C,D,E)	6-7	Reactor Outlet	340	101	19.89
4	E-1802	8-9	Reactor Outlet down stream	95	56	3.20
5	E-1803	9-10	Reactor Outlet down stream	56	38	1.25
6	E-1804	19-20	Distillation Column Feed	38	100	3.30
7	E-1805	20-21	Distillation Column Feed	100	115	0.88
8	E-1805	31-33	Distillation Column Bottom	168	155	0.88
9	E-1804	33-34	Distillation Column Bottom	155	100	3.30
10	H-1802	29-30	Boiler Recycle	169	173	6.09
11	E-1806	23-24	Column Distillate	110	58	2.49
12	E-1807	24-25	Column Distillate	58	38	0.39

Fig. 2 shows the HEN of the base-case. The utility consumption of NHU with a relatively simple heat exchanger network is not minimal. The Reactor Outlet and Column Distillate streams are cooled using a water Cooler and an Air cooler, respectively. The Boiler Recycle and Reactor Inlet streams use the hot utility service (Fired heaters) for heating. The heat transfer between furnaces using Fuel gas and Boiler Recycle and Reactor Inlet streams is the reason for the CO_2 emissions.

The composite curve in the base-case is shown in Fig. 3(a). According to Fig. 3a, the hot (red) and cold (blue) composite curves have a relatively large distance from each other and the closest distance is at $\Delta T_{min.}$=53˚C. The Large vertical distance between curves causes less heat to be recovered in the process. To reach the target temperature, cold streams above the pinch with high temperatures use Q_H=10.49 MW to reach the target temperature. In the same way, hot streams at low temperatures use Q_c=7.33 MW cold utility services. The Boiler Recycle stream entering the bottom of the Stripper is heated from 169 to 173˚C and is located above the pinch in the almost horizontal line of the cold composite curve in Fig. 3(a). The first branch of this flow exchanges heat with the Reactor Outlet (Stripper Feed) stream and easily reaches its target temperature, but in the base state, a furnace has been used to heat the second branch. The temperature of the Reactor Inlet stream increases from 276 to 340 °C using Furnace H-1801. If the modified composite curve distance is less than the base-case distance, less heat will be required to reach the target temperature.

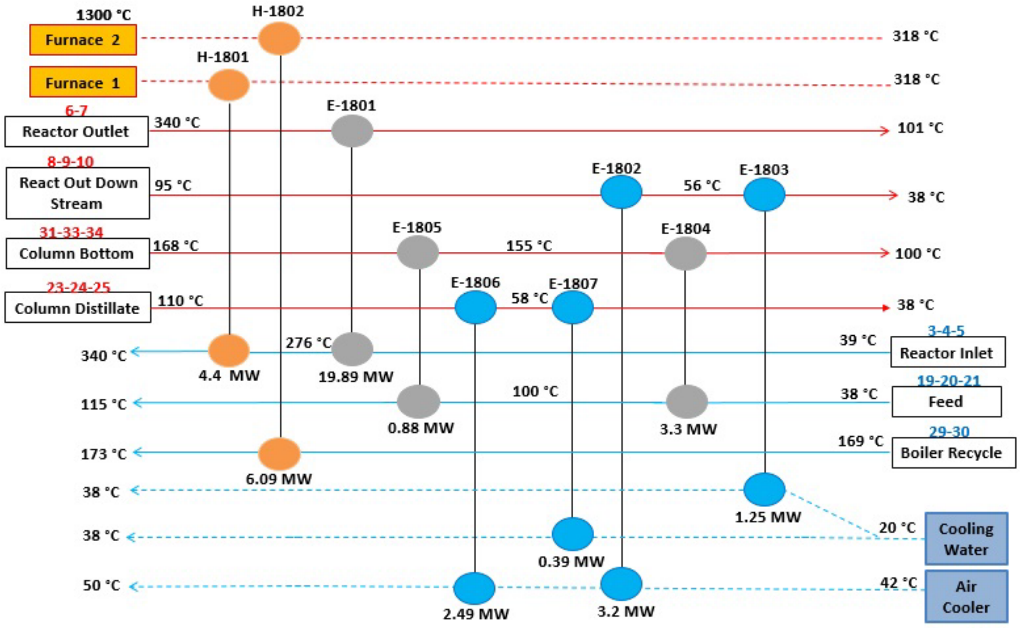

Fig. 2. HEN of the base-case

Fig. 3(b) shows the composite curve in the optimum $\Delta T_{min.}$=12°C. The cold and hot composite curves are closer to each other compared to Fig. 3(a). Therefore, heat recovery was increased within the HEN and the consumption of cold and hot utilities has been considerably reduced by 57.8 and 40.4% compared to the base-case, respectively.

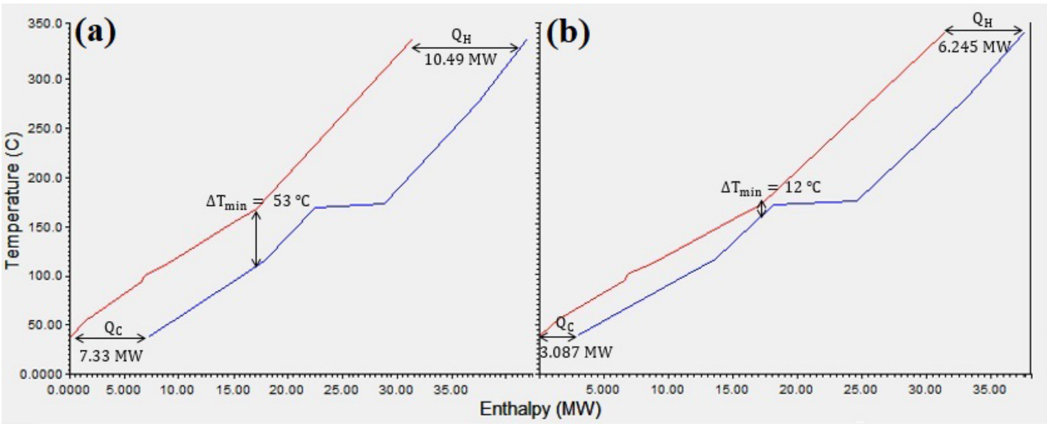

Fig. 3. Composite curves (a) base-case (b) optimal $\Delta T_{min.}$

The calculation of optimal temperature difference is described in Section 3.2. The grand composite curve is shown in Fig. 4.

Fig. 4(a) shows the grand composite curve at $\Delta T_{min.}$=53°C and Fig. 4(b) shows the grand composite curve at $\Delta T_{min.}$=12°C, respectively.

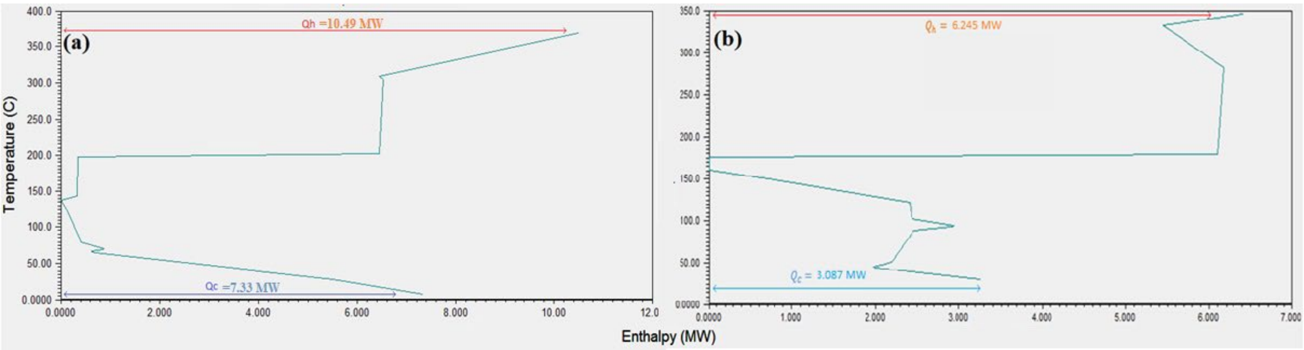

Fig. 4. Grand composite curves (a) base-case (b) optimal $\Delta T_{min.}$

The DFP (Driving Force Plot) is shown in Fig. 4. Fig. 5(a) shows the DFP of the base-cae at $\Delta T_{min.}$=53°C and Fig. 5(b) shows the DFP at optimal $\Delta T_{min.}$=12°C. The red and the black lines of DFP show heat exchangers deviating from each other. The deviant heat exchangers from the driving force line in the base-case (Fig. 5(a)) are process-to-process heat exchanger E-1805 which is the heat exchanger of the distillation column feed. Fig 5(b) indicates the deviant heat exchangers from the driving force line in the optimal $\Delta T_{min.}$=12°C: the process-to-process heat exchanger E-1801 which is over reactor outlet stream, and furnace H-1801 which is over reactor inlet stream. The deviant heat exchangers should be modified to approach the red line.

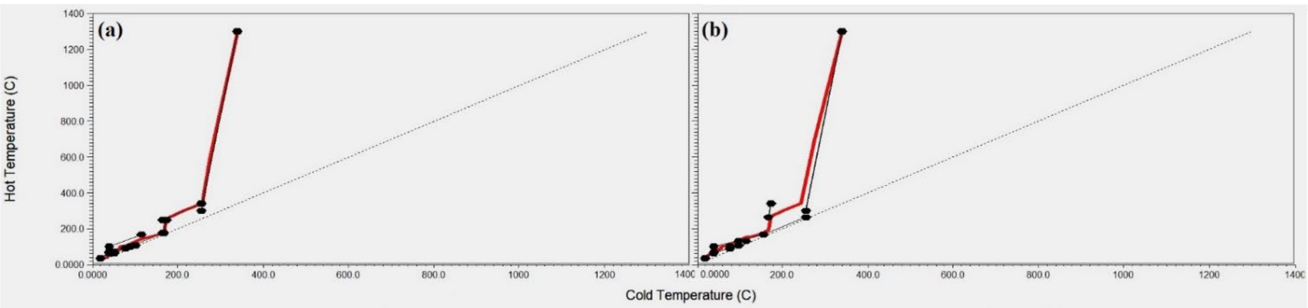

Fig. 5. Driving force plots (a) base-case (b) optimal $\Delta T_{min.}$

3.1.1. CO_2 emission calculations

The amount of CO_2 emission in the base-case is calculated according to equations 1 to 3. The net heat value of Fuel gas is approximately 46,000 kJ/kg with 82% fuel carbon and an ambient temperature of 25°C. The temperature of stack exhaust gas and the theoretical flame temperature of Fuel gas are 318 and 1975°C, respectively. The calculated amounts of CO_2 released from the H-1801 and H-1802 are 1219 kg/h and 1687 kg/h, respectively. Therefore, the total amount of CO_2 emissions is 2906 kg/h for the base-case.

3.2. Scenario I: HEN modification

Some amounts of energy are wasted in the HEN since the unit design is not optimal. In this scenario, using the pinch analysis, maximum energy recovery in the HEN and the corresponding reduction of CO_2 emissions have been investigated. $\Delta T_{min.}$ should be optimized to achieve more energy recovery in the HEN and reduce fuel consumption as well as reduce CO_2 emissions. Therefore, $\Delta T_{min.}$ was changed from 2 to 18°C with an interval of 2°C to select the optimum $\Delta T_{min.}$ resulting in the lowest Total Cost. Fig. 6 shows the process to reach optimum $\Delta T_{min.}$=12°C.

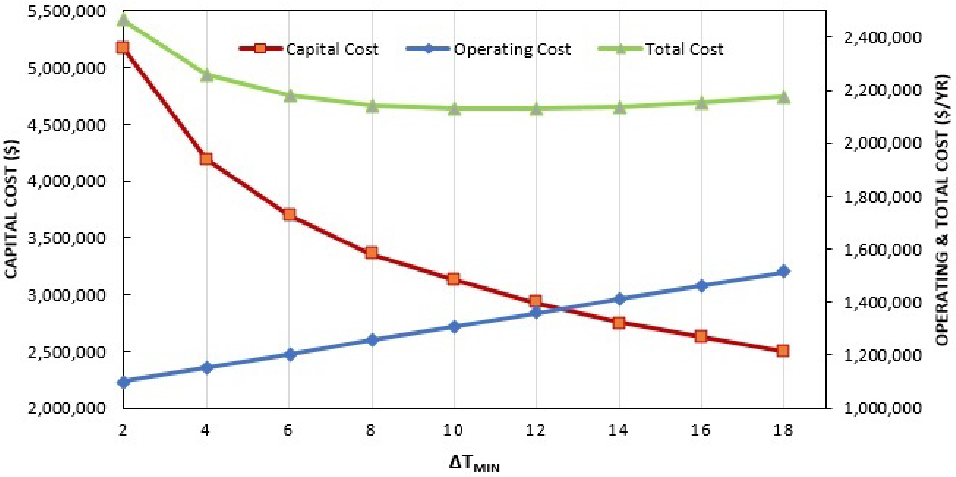

Fig. 6. Capital, operating and total costs versus $\Delta T_{min.}$

The lower $\Delta T_{min.}$ is the reason for the closer the hot and cold curves and thermal recovery will increase. As a result, the CO_2 emission will be reduced from 1842 kg/h at $\Delta T_{min.}$=18˚C to 1475 kg/h at $\Delta T_{min.}$=2˚C. By reducing the amount of $\Delta T_{min.}$, heat recovery increases and more surface area of heat exchangers is required, which increases capital costs. The operating costs, which mostly include energy consumption in utility services decrease by reducing $\Delta T_{min.}$ since heat recovery increases in the network. Therefore, $\Delta T_{min.}$ has an optimum which considered for this condition. The total annual costs are considered the main parameter to determine the optimal $\Delta T_{min.}$. Fig. 6 shows that with the decrease of $\Delta T_{min.}$ from 18 to 2˚C the total costs first decrease and then increase. Therefore, there is an optimum for Total Cost at $\Delta T_{min.}$=12˚C.

3.2.1. HEN synthesis

After achieving the optimum ΔT_{min}, synthesis of HEN at $\Delta T_{min.}$=12˚C is considered as the last step of the scenario. Three modified designs for HEN are shown in Fig. 7. The thermal and economical specifications of the base-case and modified designs are given in Table 2. Capital costs include process equipment such as heat exchangers, furnaces, pumps, tanks, vessels, and pipelines. The operating costs include fuel and energy supply costs, equipment repairs and maintenance, personnel salary and insurance, etc. Total cost includes the sum of capital cost and operating costs per useful life of the plant calculated by the software.

The Q_H=10.49 MW is the sum of the heat transferred from two furnaces to the Boiler Recycle and Reactor Inlet streams. The value of Q_C=7.33 MW is also equal to the sum of the heat released by the cold utility services from the Reactor Out downstream and the Column Distillate.

Design No.1 (Fig. 7(a)) includes seven process-to-process heat exchangers, four cold heat exchangers, and one thermal furnace. Design No.2 (Fig. 7(b)) includes seven process-to-process heat exchangers, two cold exchangers, and one thermal furnace. Design No.3 (Fig. 7(c)) including six process-to-process heat exchangers, two cold heat exchangers, and one thermal furnace has the lowest total annual costs among the three Designs. Design No.3 has the largest surface area of heat exchange and the surface area of the process-to-process heat exchangers has increased by 85% compared to the base-case. In scenario I, the operating cost has been reduced from 2,145,709 $/yr in the base case to 1,341,857 $/yr in Design No.3. In fact, 803,850 $/yr economical savings will be achieved in the operational costs of Design No.3. The payback time for this design is 2.92 years. CO_2 emissions are reduced by 41.36% choosing this design of HEN.

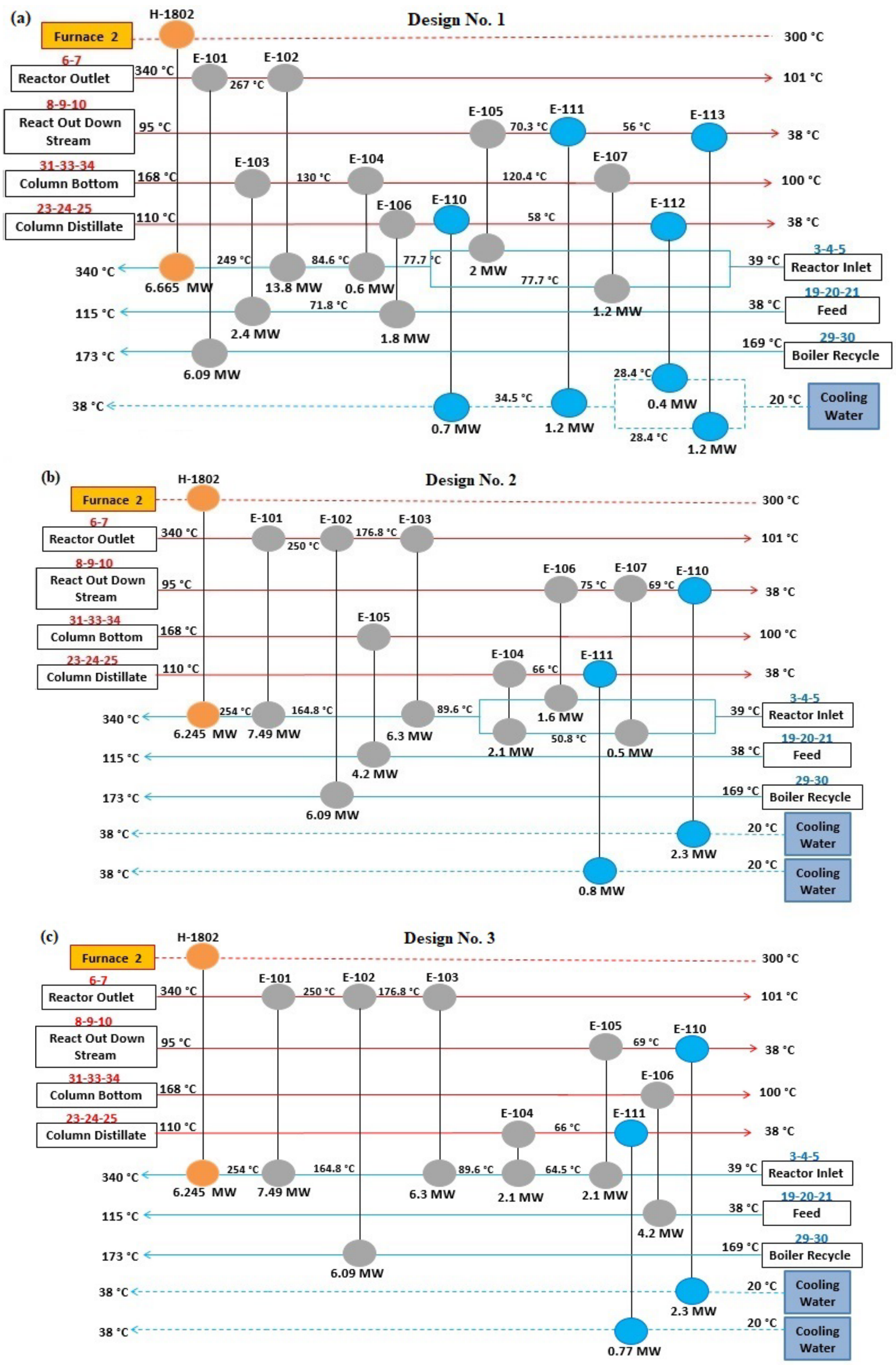

Fig. 7. Modified HEN (a) design No.1 (b) design No.2, and (c) design No.3

Table 2. Economic and thermal specifications and payback time of modified designs

Design No.	Q_H (MW)	HE surface area (m^2)	Capital cost (USD)	Operating cost (USD/yr)	Total cost (USD/yr)	CO_2 emission (kg/h)	Payback time (Yr)
Base-Case	10.49	8,032	1,302,000	2,145,709	2,489,136	2906	--
1	6.665	14190	3,725,000	1,356,363	2,339,025	1846	3.06
2	6.245	14750	3,564,000	1,485,661	2,425,749	1704	3.42
3	6.245	14900	3,655,000	1,341,857	2,305,912	1704	2.92

The amount of energy required is provided by furnace H-1802 and furnace H-1801 is out of service. There is heat crossing through the pinch in Design No.1 caused an increase in energy consumption in the cold and hot utility services by 1.3% and 6.7%, respectively. Design No.1 is not suitable since it has higher total costs and a longer payback period time compared to Design No.3. Modified design No.2 has fixed the defect in Design No.1 due to the heat crossing through the pinch since the Reactor Inlet stream splits into two branches in modified designs No.1 and 2 but modified design No. 3 does not have any split streams. The utility targets are the same as optimum $\Delta T_{min.}$=12°C. Design No.2 is not acceptable since it has higher total costs and a longer payback time compared to Design No.3. Design No.3 has no cross-pinch heat transfer, and the total costs of the unit are lower than designs No.1 and 2 and the payback period time is also shorter than Design No.3. Designs No.1 and 2 have split stream, but Design No.3 does not have any split streams. Therefore, Design No.3 has a simpler structure than the previous two designs.

3.3. Scenario II: Fuel switching

The appropriate solutions to reduce greenhouse gas emissions are changing the fuel consumed in furnaces in refinery units and using a less polluting fuel with a higher heat value. Table 3 shows the NHV, Carbon percent (C%), and the Cost of some commonly consumed fuels in industrial units.

Natural Gas has the highest NHV with a cost of 4.21 $/GJ in Table 3. The lowest cost is for Coal with 1.61 $/GJ and the lowest amount of NHV. The fuel consumption is reduced from 950 kg/h to 850 kg/h using Natural Gas instead of Fuel Gas with a 10.5% reduction in fuel consumption. The CO_2 emission of natural gas calculated from equation 1-3 for H-1801 is decreased from 1219 kg/h to 1011 kg/h for and from 1687 kg/h to 1431 kg/h for H-1802 for fuel switching from Fuel Gas to Natural Gas since Natural Gas has the lower percentage of carbon compared to Fuel Gas. Therefore, natural gas is a good substitution for fuel gas in this unit since it has a higher heat value and a 16% reduction of CO_2 emissions.

Table 3. Net Heat Value (NHV), Carbon percent (C%), and the Cost of common fuels

Fuel	NHV (kJ/kg)	C%	Cost* ($/GJ)
Fuel Gas	46000	82	7.5
Fuel Oil	39600	87	9.9
Natural Gas	51400	76	4.21
Coal	30000	> 90	1.61

* The price is based on the daily exchange of Persian Gulf FOB (Free On Board). FOB term is used to indicate when liability and ownership of goods are transferred from a seller to a buyer during shipping.

The Fuels information is given in Table 4. In fuel switching, 43% will be saved in fuel price per year since the price of Natural Gas is 0.128 $/kg (37%) cheaper than Fuel Gas.

Table 4. Heat value and price of two fuels consumed

Fuel	Fuel consumed in H-1801 (kg/h)	Fuel consumed in H-1802 (kg/h)	Total fuel consumed (kg/h)	CO_2 emission (kg/h)	Cost* ($/kg)	Fuel cost ($/yr)
Fuel Gas	400	550	950	2906	0.345	2,871,000
Natural Gas	358	492	850	2442	0.216	1,611,000

* The price is based on the daily exchange of Persian Gulf FOB (Free On Board)

Natural Gas is chosen as the alternative fuel because of its higher net heat value, fewer amount of emissions, easier access, and the lowest price of Natural Gas in Iran. Therefore, less Natural Gas fuel will be consumed in both furnaces referring to Table 4 to provide the required heat because of the higher heat value of Natural Gas. Natural Gas application in furnaces is preferred to Fuel Gas from economical point of view, too.

If the second scenario is combined with the first scenario (using Natural Gas instead of Fuel gas and modifying the HEN according to Figs. 5(a) and 5(b)), a greater amount of CO_2 emission reduction will be achieved. The amount of CO_2 emissions will decrease from 2906 to 1435 kg/h and a 50.6% emission reduction will be obtained compared to the base-case.

CO_2 emissions will be significantly reduced (41.36%) using optimal design with $\Delta T_{min.}$=12°C. Changing the fuel of the two furnaces and using natural gas instead of Fuel gas will slightly reduce CO_2 emissions. The emissions reduction reaches the maximum value (50.6%) by combining the two scenarios. Considering no capital cost for the second scenario, the payback time for the combined first and second scenarios will be 2.86 years.

3.4. Scenario III: Economizer design

Thermal energy is largely wasted from the Flue gas of the furnace stack. In this scenario, the installation of the economizer in the stack section and the corresponding energy recovery are investigated using Aspen HYSYS and Aspen Energy Analyzer V.11 simulation software.

Table 5 presents the thermal characteristics of furnaces H-1801 and H-1802 at base-case. The fuel consumption is 400 and 550 kg/h in furnaces H-1801 & H-1802, respectively. Complete combustion of fuels with 15% excess air produces 8015 kg/h and 10878 kg/h of the Flue gas including CO_2, H_2O, N_2, and O_2 at stack temperature of 318°C.

Table 5. Thermal characteristics of inlet and outlet streams of unit furnaces

Furnace	Process stream	Supply temperature (°C)	Target temperature (°C)	Flue gas flow rate (kg/h)
H-1801	Reactor Inlet	276	340	**8015**
H-1802	Bottom Recycle	169	173	**10878**

The temperature of the Reactor Inlet stream in Table 5 increases from 276 to 277.2°C in H-1801, whereas the temperature of the Boiler Recycle stream increases from 169 to 169.4°C in H-1802 by installing the economizer. Therefore, thermal energy will be recovered 0.1 MW in H-1801 and 0.5 MW in H-1802. The CO_2 emission decreases from 1219 to 1191kg/h and 1687 to 1554 kg/h in furnaces H-1801 and H-1802, respectively. The overall CO_2 emission will be reduced by 5.5% for both furnaces. Installing the economizers adds $ 116,000 to the unit capital costs, but it annually reduces 163,000$ in operating costs due to saving fuel consumption. The payback time for this scenario is 0.71 years. Table 6 shows the conditions after the economizer installation.

Table 6. The steady state conditions of the streams after installing the economizer

Furnace	Flue Gas Flow Rate (kg/h)	Heat Load (MW)	Fuel Consumption (kg/h)	Economizer Cost ($)
H-1801	7400	4.3	390	**44,000**
H-1802	10008	5.6	506	**72,000**

Economizer design has made it possible to preheat Reactor Inlet and Boiler Recycle streams by heat recovery from Flue gas streams to reduce the thermal load and fuel consumption in the H-1801 and H-1802 furnaces. Consequently, CO_2 emission decreases by reduction in fuel consumption. Using Eq. (1), the maximum heat recovery from the outgoing Flue gas occurs when the temperature of the outlet Flue gas (T_{Stack}) reaches that of the process stream entering the corresponding furnaces.

Using Equation (4), the maximum heat recovery from furnaces H-1801 & H-1802 is calculated at 0.109 and 0.48 MW, respectively. The temperature difference (heat transfer driving force) between the stream entering the furnace and the outgoing Flue gas in H-1802 is greater than that of H-1801. Therefore, the heat recovery in furnace H-1802 is higher than H-1801.

3.5. Combination of scenarios I-III

The combination of scenarios I-III is utilized as the optimum design. In the combination of scenarios, the temperature of the Reactor Inlet stream in base-case increases from 254 to 257.2°C after the installation of economizers in the furnace in combination of scenarios (Fig. 8). The inlet is then entered into the radiation and convection sections of the furnace, leading to a reduction in the furnace duty from 6.245 in scenario I to 6.032 MW in combination design. As a result, the CO_2 emission decreases to 1386 kg/h. In other words, the final amount of CO_2 emission is reduced by 52.3% compared to the base-case.

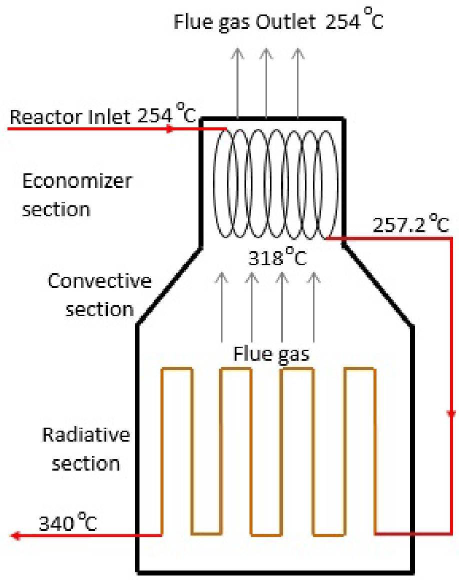

Fig. 8. A schematic representation of optimum design of H-1801

The final results of CO_2 emissions are compared in Table 7. Table 7 shows the lowest amount of CO_2 emission is for Combination of scenarios I to III.

Table 7. CO_2 emissions results

Scenarios No.	CO_2 emissions (kg/h)
Base-Case	2906
I	1704
II	1435
III	2745
Combination of I-III	1386

4. Conclusions

In this research, three scenarios have been carefully examined. Scenario I was about modifying the HEN to achieve $\Delta T_{min.}$=12°C to reduce subsequent CO_2 emissions. Scenario II was fuel switching between natural and fuel gas for CO_2 emissions reduction. An economizer installation at the furnace stack was suggested and investigated in Scenario III to increase the thermal efficiency of the furnaces and reduce CO_2 emissions. The best case was the combination of scenarios I to III (I-III). The energy consumption and CO_2 emissions decreased to 6.032 MW and 1386 kg/h in the Combination of scenarios I-III, respectively. Integrating all three scenarios (combination of scenarios I-III) showed the maximum 3.4 and 52.3% reduction of energy consumption and CO_2 emissions, respectively. As future steps, preheating the column feed using the wasted heat inside the network will reduce energy consumption and CO_2 emissions. The reduction of the column pressure will reduce the thermal load of the reboiler and the reduction of furnace flue gas to acid dew point temperature will obtain more thermal recovery in future studies.

Nomenclature

Acronyms

C	Carbon
CEPA	Carbon Emission Pinch Analysis
DFP	Driving Force Plot
E	Exchanger
FOB	Free On Board
H	Heater
HE	Heat exchanger
HEN	Heat Exchanger Network
MER	Minimum Energy Requirement
MW	Mega Watt
NHU	Naphtha Hydro treating Unit
NHV	Net Heat Value
T	Temperature
TFT	Theoretical flame temperature

Latin symbols

$\dot{m}$	Flue gas flow rate
Q	Heat
$\dot{Q}$	Heat flow rate

Greek symbols

Δ	Increment
φ	Thermal efficiency
α	Constant coefficient

Subscript

C	Cold
H	Hot
min.	minimum

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