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Application of Pinch Analysis for Energy Saving and Reducing Gas Emissions Based on Mathematical Model in the Hydrocracking Unit

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Abstract: Pinch analysis approach of the heat exchanger network in the hydrocracking unit was carried out to save energy consumption and reduce gas emissions simultaneously. This method based on mathematical model of the hydrocracking unit for a heat exchanger network using LINGO program to achieve the minimization of environmental impacts and the reduction of energy cost. The presented energy demands for the heat exchanger network are 20.38 MMBtu/hr and 26.52 MMBtu/hr for heating and cooling loads, respectively. The current analysis shows a huge opportunity in order to decrease the energy consumption of the hydrocracking process at a minimum temperature difference of 60°F. The final results display the save of energy is about 44% for heating utility in the furnace, while the save for cooling utility is around 34%. All these savings of the energy will lead to saving in the energy costs of about 1,415,078 USD$/yr. Similarly, reducing gas emissions in the hydrocracking unit from 12,301.67 to 6,854.77 metric tons/year equates to a reduction of 44.3%.

Keywords: Heat Exchanger Network; Energy Saving; Gases emissions; Mathematical Model; Hydrocracking Unit

1. Introduction:

Higher energy prices that are used as supply-to-units operations in oil refining and stricter limits on gas emissions to the environment have led to an increased interest in energy saving. Energy use and the generation of harmful emissions have become the important challenges of modern society due to the use of fossil fuel resources or the use of other associated resources. The definition of an energy recovery potential and energy improvement with pollution reduction play a pioneering role in contributing to the solution of the related problems through presenting new methodologies [1, 2].

Hydrocracking is considered the secondary refinery process, and it is one of the most widespread processes that converts heavy oil fractions into lighter products and high quality middle distillates such as LPG, naphtha, kerosene and diesel. The process takes place in a hydrogen-rich atmosphere at pressures (35-200 bar) and at high temperatures (260-420 °C). The reactions of cracking and hydrogenation consider the main hydrocracking reactions, which occur in the presence of a catalyst with operating conditions such as pressure , temperature, and space velocity [3]. The hydrocracking processes in the synthesis of various nanomaterials used in hydrocracking catalysts were well presented [4]. In another research, the pinch and exergy analysis was performed for the diesel hydrotreating unit operated in two modes. It was concluded that the proposed method helped the design of a new plant [5]. Energy management and fuel switching were applied for hydrotreaters, and the maximum percentage of energy-saving was 37% for hot and cold utilities [6].

Heat integration technique is one of the methods that is studied to improve energy use and decrease energy waste in chemical processes. Goodarzvand-Chegini et al. (2011) applied pinch technology to the hydrocracking process for recovering the maximum waste energy while maintaining stable production. The results showed about $870 *103 annual savings in energy costs of the hydrocracking process [7]. Zhang et al. (2015) studied the optimization of materials and energy on the refining site scale based on a multi-period mathematical model for reducing energy. They focused the energy investigation on achieving better economic performance. They found the economic benefits were demonstrated by the simultaneous optimization of the refining site scale [8]. Morrow et al. (2015) studied the improvement of energy efficiency for the refining industry with CO2 emission reduction as an environmental effect. The results showed about 1500 (PJ/yr) fuel savings for the plant and 650 (GWh/yr) of electricity savings, which represent potentially cost-effective. This amount of reduction reached 85 MteCO2/yr [9]. Goodarzvand-Chegini and GhasemiKafrudi (2017) improved the heat exchanger network in a hydrocracking process to increase heat efficiency. The results showed that the integration of pinch and exergy analysis in the hydrocracking process provides 436 kW power generation from high pressure reduction through HPRT installation and also 5.96MW recoverable exergy losses from hot stock flue gasses [10]. Abdul Aziz et al. (2017) applied algebraic algorithms to reduce carbon dioxide based on pinch analysis for industrial sites. They proposed a systematic framework and focused on the resources, power system, total site, and CO2 emissions [11]. Gao et al. (2018) studied the recovery rate of carbon dioxide and its purity in the crude synthesis gas. The results were from 35% to 92% as an improvement of the process compared to the current process. While the carbon dioxide was reduced from 1014 kJ / kg CO2 to 388 kJ / kg CO2 [12].

Eman and Soad (2018) studied the Heat Exchangers Network of the existing naphtha treating unit to minimize the cost of the energy and maximize the emission reduction. They used the mathematical solver (GAMS) to achieve this task. The results were the energy consumption reduction from 27% to 18% while the emissions of gasses were from 21% to 12% compared to the existing treating unit [13]. Cucek et al. (2019) studied heat exchanger networks within processes and total sites for retrofitting and to achieve lower energy consumption, cost savings, and emission reduction. They used an approach for retrofitting of existing HENs based on heuristics, thermodynamic analysis, and insights – Pinch Analysis [14]. Babaqi (2019) studied the crude distillation unit for energy savings and gas emissions reduction based upon a mathematical model using the LINGO program. He found that the heating and cooling duties were about 6.92% and 17.26% savings, respectively. Likewise, reducing the greenhouse gas emissions to 26,133.79 metric tons/yr [15]. Wang et al. (2020) studied heat exchanger network retrofit to maximize energy savings. They used a two-stage method for the heat exchanger network and a retrofit two-stage method. The first stage is based on the structure of the shifted retrofit thermodynamic grid diagram (SRTGD) to minimize the utility cost and investment. The second stage was based on a particle swarm optimization (PSO) algorithm and was to select the minimizing payback period. The obtained results were more the effectiveness of the method compared to previous retrofit applications, of about 11.6% and 21.7% decreasing for case1 and case2, respectively [16]. Mrayed et al. (2021) studied heat exchanger networks of crude oil distillation units to save energy via retrofit of the network. They used pinch analysis that helps in minimizing the energy losses and provide more efficient heat exchanger networks. The results were about 67.5 MW of cooling and heating utility savings compared to the existing process utility of 148.6 MW. This represents an approximately 45% reduction in heating utility requirements, while CO_2 emissions were 1079 kg CO_2/h [17]. Boldyryev and Gil (2021) studied the debottlenecking of hydrocracking units for energy saving and carbon dioxide reduction through improved energy recovery. They proposed the systematic reduction of energy consumption in the process by an energy audit of grid diagrams. They found the energy consumption was cut by 54% of the energy consumption with a payback period of 9.5 months for the process modifications. While reduction of carbon dioxide shows annual savings, about 18,915 tons of CO_2 [18]. Biermann et al. (2022) studied energy supply for partial carbon capture in the process industry. They sought out the ideal combination of heat sources, taking into account the already-existing site energy system using a multi-period mixed-integer linear programming technique. They discovered that this raised the price of providing heat as well as emissions by 7 to 26% and 9 to 66%, respectively [19]. Tang et al. (2022) studied the design optimization of processes for decreasing energy consumption in the industrial energy systems. A mixed integer nonlinear programming framework and an industrial energy systems superstructure were together used to conduct design optimization for the energy system. Their study revealed that total annual cost and annual CO2 emission have decreased from the conventional optimized design by 10.96% and 19,845 tons, respectively, compared to the conventional optimized design [20].

This paper represents the study analysis of hydrocracking unit to energy saving of heat exchangers network with reduction of gases emissions to the environment at the lowest operating costs. This technique was used based on a new mathematical model via pinch analysis and solved this model using LINGO program.

2. Process Description

The hydrocracker unit is important in oil refineries and the purpose of the hydrocracker unit is to upgrade the low value gas oil product from vacuum column to high value products like naphtha, diesel and kerosene. It comprises the section of a makeup hydrogen compressor, a reactor section and a fractionator section.

The design fed to the plant is heavy gas oil from a vacuum column and the major products are naphtha, kerosene and diesel. The conversion is carried out of the process in two stages. The feed to first stage reactor is fresh vacuum gas oil from vacuum column and the feed to second stage reactor is unconverted oil recovered from the bottoms of product fractionator column.

The feed reacts with recycled hydrogen in reactors and in the presence of a catalyst and operating conditions such as pressure, temperature, and space velocity. The analysis was carried out for diesel maximization cases.

hydrocracking unit, which it consists of six hot streams and five cold streams for pinch analysis in the form required.

3.2 Analysis of utilities consumption and cost data:

The utilities consumption of the hydrocracking process were conducted by composite curves to identify the existing load duties on the network. Figure 2 shows heating and cooling utilities demands, which are 20.38 MMBtu/hr and 26.52 MMBtu/hr respectively. Cost of energy consumption for the existing hydrocracking process for hot and cold utilities was reported in Table 2 [15]. The annual service period (ASP) of 7920 hr was implemented [21].

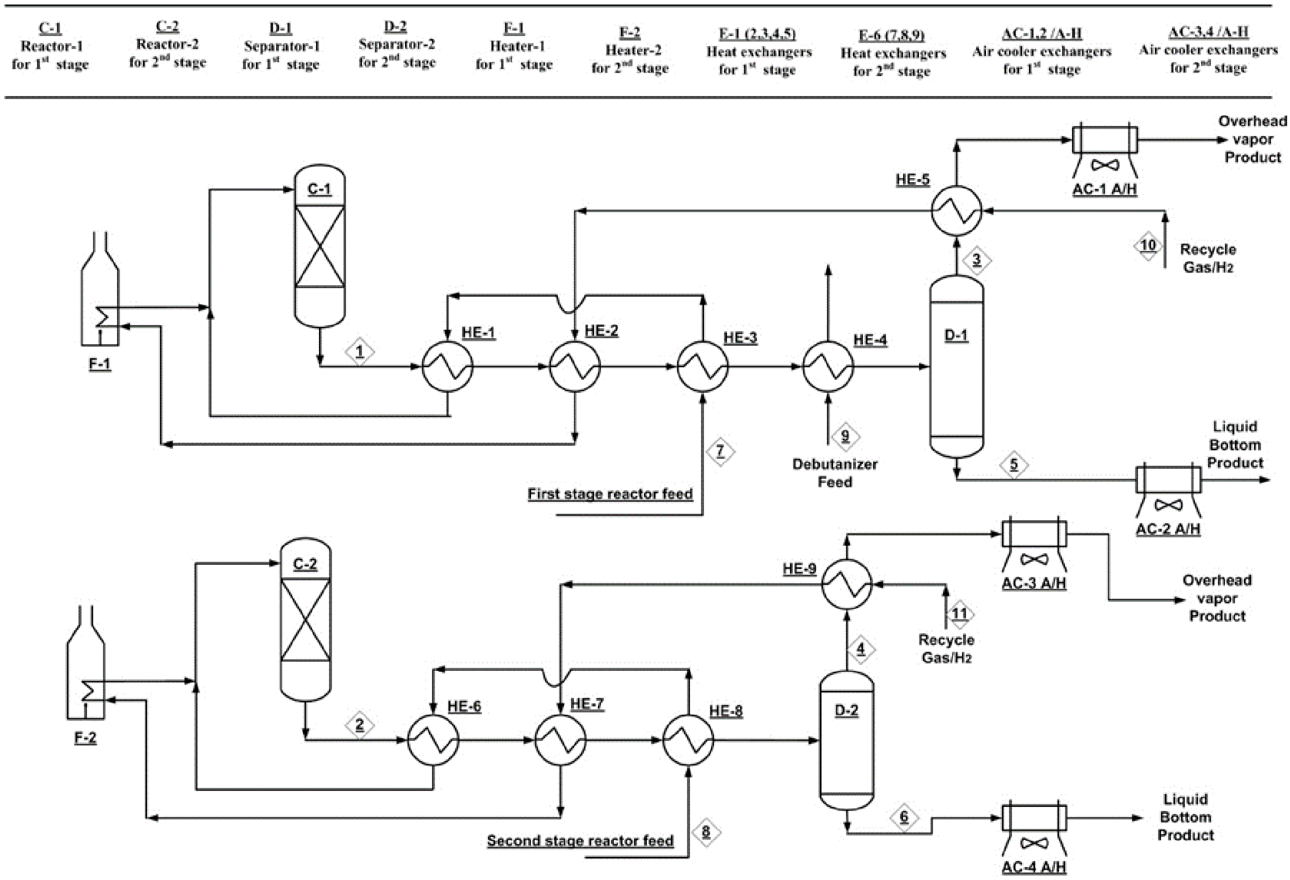

Figure 1: Flow sheet diagram of reaction section for two stages operation in hydrocracker unit

It was mainly both 1st and 2nd reactor feed/effluent circuit and also the product fractionator column streams. Figure 1 shows a flowsheet diagram of the reaction section for two stages of operation in the hydrocracker unit.

3. Methodology:

3.1 Data extraction and analysis of the process flowsheet diagram:

The process data was extracted after the getting reliable heat and mass balances of the process. For the form required of pinch analysis was estimated hot and cold stream of the process. Table 1 shows the extracted data of the

Table 1: Data of the process flowsheet diagram for heat exchanger network

Stream Name	Stream Type	Supply Temperature (°F)	Target Temperature (°F)	Heat Capacity Flowrate ((MMBtu/hr)/ °F)	Heat Flow (MMBtu/hr)
H1	HOT	780	500	0.785	219.80
H2	HOT	600	500	0.561	56.09
H3	HOT	500	428	0.481	34.66
H4	HOT	500	311	0.264	49.83
H5	HOT	390	129	0.051	13.40
H6	HOT	446	129	0.174	55.19
C1	COLD	307	660	0.357	126.05
C2	COLD	350	540	0.270	51.24
C3	COLD	125	516	0.117	45.86
C4	COLD	170	759	0.187	110.17
C5	COLD	170	669	0.179	89.52

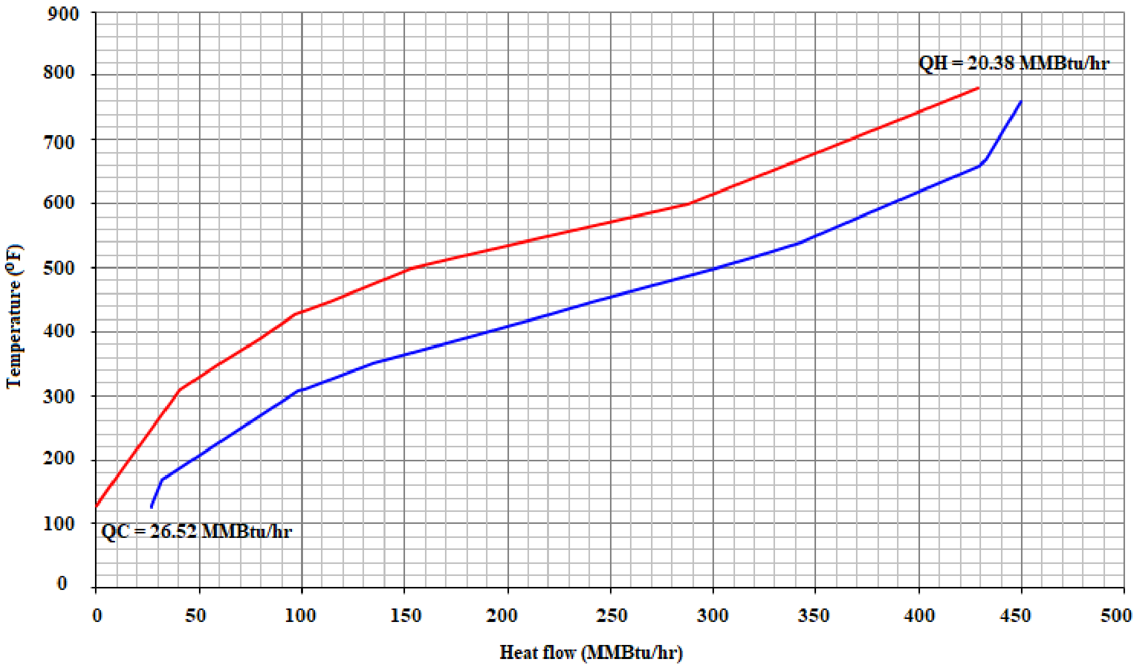

Figure 2: Composite curves for existing data of the hydrocracking process

Table 2: Utility consumption data and utilities cost

Name	Type	Utilities consumption (MMBtu/hr)	Utilities Cost $ / (MMBtu/hr)
Fuel gas	Hot	20.38	19.33
Air Cooling	Cold	26.52	0.47

3.3 Creation of the minimum utility cost model and gas emissions model:

To create the model for minimizing the utility cost of the process network via heat duties, will subject this model to constraints of heat balance for every stream of the temperature interval. For developing the formulation of the model of this case study with the helping Pinch Analysis Spreadsheet, Figure 3 was conducted. Hence, the purpose of process optimization is to minimize the value of an objective function that represents the minimum cost of heating and cooling utilities subject to a number of constraints. The form of constraint is equality expressions of the energy balance of each temperature interval, as shown in Figure 3. Temperature-interval drawing with shifted hot and cold streams of the process is shown in Figure 4.

To write the mathematical model, we need to define the following indices:

❖ For the decision variables

Let:

$Q_{H,\,min}$: be amount of heating utility (kW)
$Q_{C,\,min}$: be amount of cooling utility (kW)
C_h : The cost of heating utility
C_c : The cost of cooling utility
z = minimum cost of heating and cooling utilities ($/year) and is the objective function.

❖ For the objective function:

$$\text{Minimize } Z = (\mathrm{Ch} * \mathrm{QH,min} + \mathrm{Cc} * \mathrm{QC,min}) * \mathrm{ASP} \qquad (\mathbf{1})$$

Where ASP is an annual service period (330 days).

❖ For Constraints

All constraints are created by heat balance around temperature interval, including utilities:

$$\mathrm{Ri} - \mathrm{QH,min} = \Delta\mathrm{H\,k} \qquad (2)$$

$$\mathrm{Ri} - \mathrm{Ri} + 1 = \Delta\mathrm{H\,k} + 1 \qquad (3)$$

$$\mathrm{Ri} + 1 - \mathrm{Ri} + 2 = \Delta\mathrm{H\,k} + 2 \qquad (4)$$

$$\mathrm{Ri} + 2 - \mathrm{Ri} + 3 = \Delta\mathrm{H\,k} + 3 \qquad (5)$$

$$\mathrm{Ri} + 3 - \mathrm{Ri} + 4 = \Delta\mathrm{H\,k} + 4 \qquad (6)$$

$$\mathrm{Ri} + 4 - \mathrm{Ri} + 5 = \Delta\mathrm{H\,k} + 5 \qquad (7)$$

$$\mathrm{Ri} + 5 - \mathrm{Ri} + 6 = \Delta\mathrm{H\,k} + 6 \qquad (8)$$

$$\mathrm{Ri} + 6 - \mathrm{Ri} + 7 = \Delta\mathrm{H\,k} + 7 \qquad (9)$$

$$\mathrm{Ri} + 7 - \mathrm{Ri} + 8 = \Delta\mathrm{H\,k} + 8 \qquad (10)$$

$$\mathrm{Ri} + 8 - \mathrm{Ri} + 9 = \Delta\mathrm{H\,k} + 9 \qquad (11)$$

$$\mathrm{Ri} + 9 - \mathrm{Ri} + 10 = \Delta\mathrm{H\,k} + 10 \qquad (12)$$

$$\mathrm{Ri} + 10 - \mathrm{Ri} + 11 = \Delta\mathrm{H\,k} + 11 \qquad (13)$$

$$\mathrm{Ri} + 11 - \mathrm{Ri} + 12 = \Delta\mathrm{H\,k} + 12 \qquad (14)$$

$$\mathrm{Ri} + 12 - \mathrm{Ri} + 13 = \Delta\mathrm{H\,k} + 13 \qquad (15)$$

$$\mathrm{Ri} + 13 - \mathrm{QC,min} = \Delta\mathrm{H\,k} + 14 \qquad (16)$$

❖ For non-negativity constraints: all the variables defining the different heat flow loads are nonnegative**.**

$$\mathrm{QH,min} >= 0 \qquad (17)$$

$$\mathrm{QC,min} >= 0 \qquad (18)$$

$$\mathrm{Ri} >= 0 \qquad (19)$$

$$\mathrm{Ri} + 1 >= 0 \qquad (20)$$

$$\mathrm{Ri} + 2 >= 0 \qquad (21)$$

$$\mathrm{Ri} + 3 >= 0 \qquad (22)$$

$$\mathrm{Ri} + 4 >= 0 \qquad (23)$$

$$\mathrm{Ri} + 5 >= 0 \qquad (24)$$

$$\mathrm{Ri} + 6 >= 0 \qquad (25)$$

$$\mathrm{Ri} + 7 >= 0 \qquad (26)$$

$$\mathrm{Ri} + 8 >= 0 \qquad (27)$$

$$\mathrm{Ri} + 9 >= 0 \qquad (28)$$

$$\mathrm{Ri} + 10 >= 0 \qquad (29)$$

$$\mathrm{Ri} + 11 >= 0 \qquad (30)$$

$$\mathrm{Ri} + 12 >= 0 \qquad (31)$$

$$\mathrm{Ri} + 13 >= 0 \qquad (32)$$

For the gas emissions model**,** the formula was used for reducing emissions gases that resulted from combustion fuel for the generation of heat in furnaces as supply to the process. The formulation used to reduce emissions gases that can be an expression as [15]:

$$\mathrm{EGHG} = \mathrm{QF} * \mathrm{EFa} * \mathrm{CFa} * \mathrm{ASP} \qquad (33)$$

Where;

E_{GHG}: amount of emissions greenhouse gases (CO_2, CH_4 and N_2O) metric tons/year
Q_F: quantity of reduction energy (MMBtu/hr)
E_{Fa}: quantity of emission gas through the combustion of fuel gas (Kg- gas/MMBtu)
C_{Fa}: conversion factor (kilograms to tons)
ASP : annual service period (330 days).

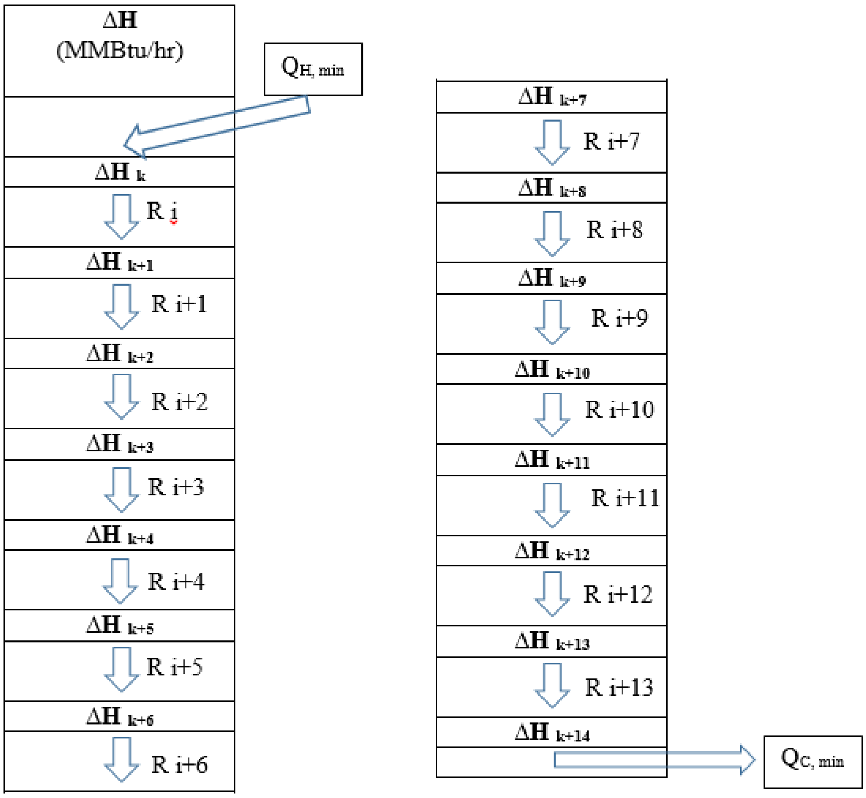

Figure 3: develop mathematical model

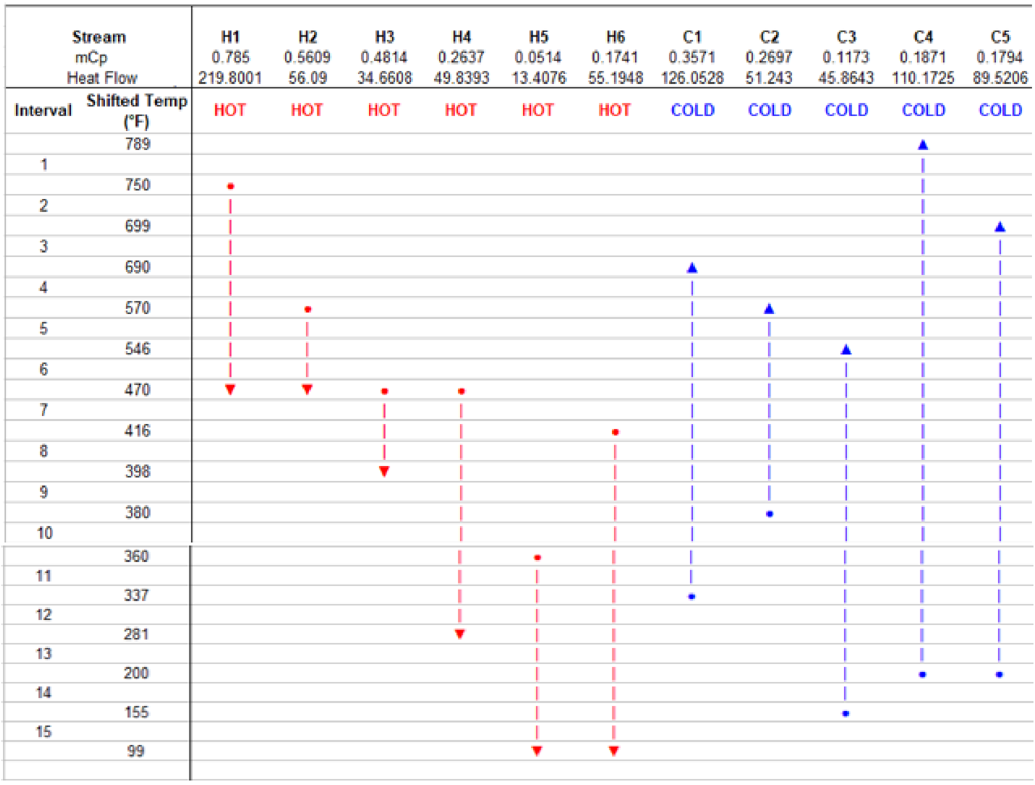

Figure 4: Temperature-interval diagram and shifted streams of hot and cold

Emissions gases through combustion of fuel gases are methane, carbon dioxide and nitrous oxide. Table 3 shows emission factors (E_{Fa}) through combustion of consumed fuel gas that is used in furnaces to get the energy for hot utility [15].

Table 3: Emission factors through combustion of consumed fuel gas

Type gas	E_{Fa} values (kg/MMBtu)
CO_2	75.26
CH_4	0.003
N_2O	0.951

3.4 Selection of the minimum driving force:

The minimum driving force of this network was generated to identify the optimum temperature. The specified range of minimum temperature difference was from 20 °F to 120 °F. For ΔTmin values and taking into account the rule-of-thumb, it is selected the optimum ΔTmin = 60 °F [22]. This optimum will provide a trade-off balance between capital and operating costs of the process. Table 4 shows a specified range of minimum temperature difference with the pinch temperature and the minimum utility requirements.

5. Results and Discussion:

The first step for creating the model is identification of all streams and shifted temperature intervals in order to calculate the heat loads. Table 5 shows shifted intervals for calculating heat loads.

Figure 5 shows the relationship between varying pinch temperature versus the minimum temperature difference ΔTmin, the hot pinch temperature was 230 °F for the existing while the targeting was 170 °F. Also, the cold pinch temperature was 170 °F for the existing while the target was 170 °F. We can see in Figure 6 the relationship between varying minimum hot and cold utilities versus the minimum temperature difference (ΔTmin), where the target energy was selected at 60 °F.

Table 4: Specified range minimum temperature difference

Δ Tmin (°F)	Hot pinch (°F)	Cold pinch (°F)	Hot utility (MMBtu/h)	Cold utility (MMBtu/h)
120	600	480	29.47456	35.613884
115	600	485	23.921858	30.061182
110	280	170	22.630571	28.769895
105	275	170	21.503141	27.642465
100	270	170	20.375711	26.515035
95	265	170	19.24828	25.387604
90	260	170	18.12085	24.260174
85	255	170	16.99342	23.132744
80	250	170	15.865989	22.005313
75	245	170	14.738559	20.877883
70	240	170	13.611128	19.750453
65	235	170	12.483698	18.623022
60	230	170	11.356268	17.495592
55	225	170	10.228837	16.368161
50	220	170	9.101407	15.240731
45	215	170	7.9739766	14.113301
40	210	170	6.8465463	12.98587
35	205	170	5.7191159	11.85844
30	200	170	4.5916855	10.73101
25	195	170	3.4642551	9.6035792
20	190	170	2.3368248	8.4761488

Table 5: Shifted intervals for calculating heat loads

Shift Temperature (°F)	Interval	$T_{(i+1)} - T_i$ (°F)	mCp_{net} (MMBtu/hr)/°F)	dH (MMBtu/hr)
789				
	1	39	-0.1871	-7.295
750				
	2	51	0.598	30.4955
699				
	3	9	0.4186	3.767
690				
	4	120	0.0615	7.3752
570				
	5	24	0.3527	8.4638
546				
	6	76	0.2354	17.8874
470				
	7	54	-0.3654	-19.7338
416				
	8	18	-0.1913	-3.4438
398				
	9	18	-0.6727	-12.109
380				
	10	20	-0.403	-8.0605
360				
	11	23	-0.3517	-8.088
337				
	12	56	0.0054	0.3044
281				
	13	81	-0.2583	-20.9194
200				
	14	45	0.1082	4.8684
155				
	15	56	0.2255	12.6272
99				

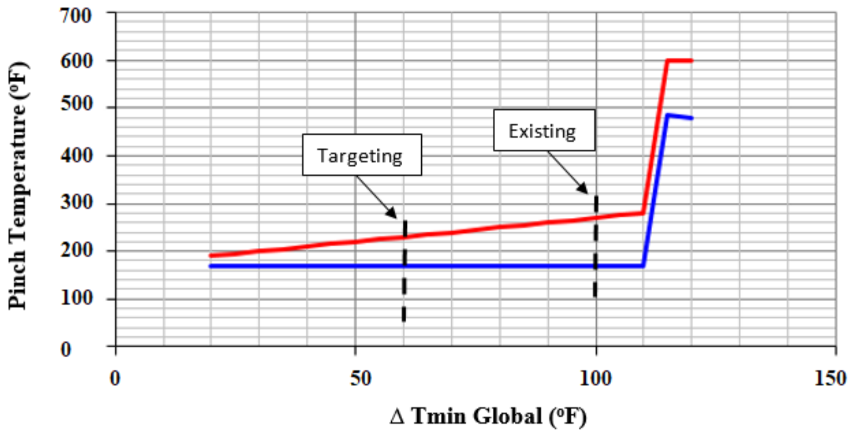

Figure 5: Relationship varying pinch temperature versus ΔTmin

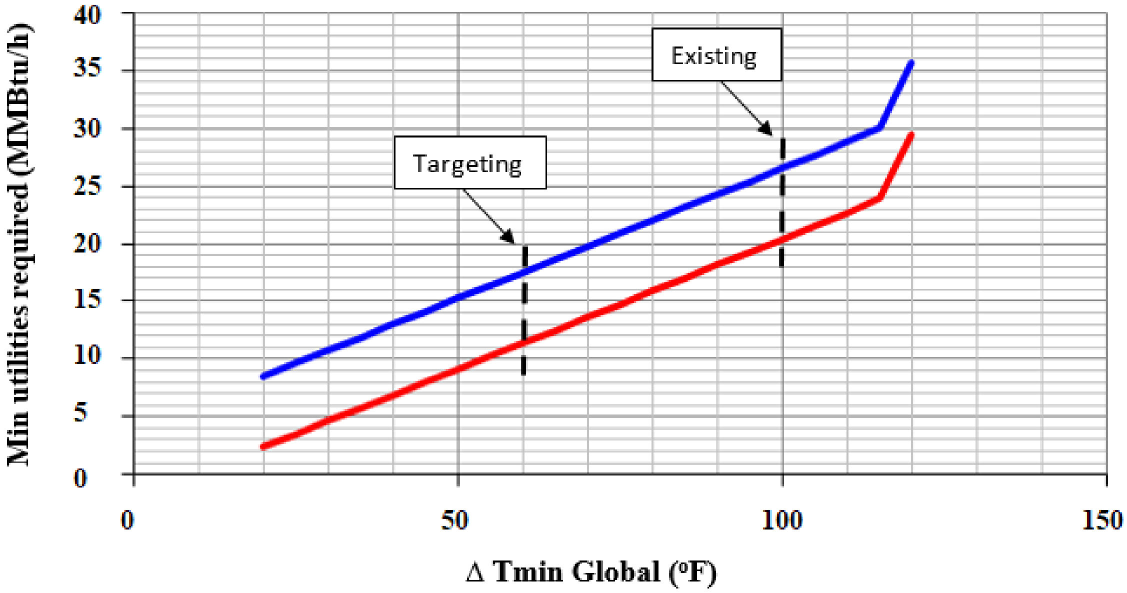

Figure 6: Relationship varying min hot and cold utilities versus ΔTmin

For evaluating the saving energy and emissions gases of the hydrocracking unit via heat integration using mathematical models, Table 6 is developed. The presented energy demand for the heat exchanger network is 20.38 MMBtu/hr and 26.52 MMBtu/hr for heating and cooling facilities, respectively.

A save in hot utility demand around 44% and this it is expected the reduction from 20.38 MMBtu/hr in the current process to 11.36 MMBtu/hr in the optimizing-process. While a save in cold utility demand around 34% and this it is expected the reduction from 26.52 MMBtu/hr in the current process to 17.5 MMBtu/hr in the optimizing the process. The total cost saving energy of this process reached 1,415,078 USD$/yr. Similarly, reducing the gas emissions of the hydrocracking unit from 12301.67 to 6854.77 metric tons/yr and this equivalent reducing of 44.3%.

Table 6: Evaluation of energy costs, saving% and emissions gases

Type	**ΔTmin °F**	**Hot Utility (MMBtu/hr)**	**Cold Utility (MMBtu/hr)**	**Cost Hot Utility (USD$/yr)**	**Cost Cold Utility (USD$/yr)**	**Reduction of emissions greenhouse gases (metric tons/yr)**
Existing process	100	20.38	26.52	3,120,048	98,718.05	12,301.67
Optimizing process	60	11.36	17.5	1,738,562	65,125.62	6,854.77
Saving %		44%	34%	-	-	44.3%

Total cost of saving energy = 1,415,078 USD$/yr

5.1. Comparing the results of this work with previous studies:

The comparison of the results of this work with previous studies related to the application of the pinch analysis for energy saving and emissions gases are shown in Table 7. It is clearly observed that the hot utility saving of the process reached 44% and the cold utility saving, about 34%, are higher compared with the other authors [15, 23]. In addition, this work linked the hot and cold utilities with emission gasses simultaneously to improve process performance, which led to reducing emissions by about 44.3% of the hydrocracking unit, while the other authors did not mention it.

Table 7: Comparison results between this work and previous studies of the process

Type of process	ΔTmin	Total Hot Utility Saving %	Total Cold Utility Saving %	Reduction of emissions%	References
Crude distillation unit	50 °F	6.92%	17.26%	-	[15]
Hydrocracking unit	94 °F	18%	12.3%	-	[10]
Hydrocracking unit	60 °F	44%	34%	44.3%	This work

6. Conclusions

The hydrocracking unit's energy integration is being researched to reduce gas emissions while simultaneously improving energy consumption and

Conflicts of Interest: "The authors declare that they have no conflicts of interest to report regarding the present study."

cost-saving options.

The method based upon mathematical model using LINGO program to achieve the energy costs reduction besides minimization of environmental effects that generated from the hydrocracking unit. The presented survey shows a great opportunity to decrease energy consumption with minimizing temperature difference (ΔTmin) of 60 °F. The results show a save of energy is about 44% for heating utility in furnace, while a save of cooling utility is around 34%. All these savings of the energy will lead to savings of energy costs of about 1,415,078 USD$/yr. To improve the environment, it has reduced the gas emissions of the hydrocracking unit from 12,301.67 to 6,854.77 metric tons/yr and this equivalent reducing of 44.3%. Emissions gases from the combustion into the environment include carbon dioxide (CO_2) and methane (CH_4) and nitrous dioxide (N_2O).

Appendix

Global optimal solution found.
Objective value: 1803687.
Infeasibilities: 0.000000
Total solver iterations: 0

Variable	Value	Reduced Cos
CH	19.33000	0.000000
QHMIN	11.35620	0.000000
CC	0.4700000	0.000000
QCMIN	17.49560	0.000000
ASP	7920.000	0.000000
EGHG	0.8655014	0.000000
QFUEL	11.35620	0.000000
EF	76.21400	0.000000
CF	0.1000000E-02	0.000000
EGHG_EX	1.553241	0.000000
QFUEL_EX	20.38000	0.000000
S_HEATING	44.27772	0.000000
QHEX	20.38000	0.000000
S_COOLING	34.02866	0.000000
QCEX	26.52000	0.000000
S_EMISSIONS	44.27772	0.000000
COST_HU	1738562.	0.000000
COST_HUEX	3120048.	0.000000
COST_CU	65125.62	0.000000
COST_CUEX	98718.05	0.000000
TOTAL_COST_SAVING_ENERGY	1415078.	0.000000
RI	4.061200	0.000000
RI_1	34.55670	0.000000
RI_2	38.32370	0.000000
RI_3	45.69890	0.000000
RI_4	54.16270	0.000000
RI_5	72.05010	0.000000
RI_6	52.31630	0.000000
RI_7	48.87250	0.000000
RI_8	36.76350	0.000000
RI_9	28.70300	0.000000

RI_10	20.61500	0.000000
RI_11	20.91940	0.000000
RI_12	0.000000	156816.0
RI_13	4.868400	0.000000

Global optimal solution found.
Objective value: 1803687.
Infeasibilities: 0.000000
Total solver iterations: 0

Variable	Value	Reduced Cost
CH	19.33000	0.000000
CC	0.4700000	0.000000
ASP	7920.000	0.000000
EF	76.21400	0.000000
CF	0.1000000E-02	0.000000
QHEX	20.38000	0.000000
QCEX	26.52000	0.000000
QHMIN	11.35620	0.000000
QCMIN	17.49560	0.000000
QFUEL_EX	20.38000	0.000000
QFUEL	11.35620	0.000000
EGHG	6854.771	0.000000
EGHG_EX	12301.67	0.000000
S_HEATING	44.27772	0.000000
S_COOLING	34.02866	0.000000
S_EMISSIONS	44.27772	0.000000
COST_HUEX	3120048.	0.000000
COST_HU	1738562.	0.000000
COST_CUEX	98718.05	0.000000
COST_CU	65125.62	0.000000
RI	4.061200	0.000000
RI_1	34.55670	0.000000
RI_2	38.32370	0.000000
RI_3	45.69890	0.000000
RI_4	54.16270	0.000000
RI_5	72.05010	0.000000
RI_6	52.31630	0.000000
RI_7	48.87250	0.000000
RI_8	36.76350	0.000000
RI_9	28.70300	0.000000
RI_10	20.61500	0.000000
RI_11	20.91940	0.000000
RI_12	0.000000	156816.0
RI_13	4.868400	0.000000

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