STUDIA UNIVERSITATIS BABES-BOLYAI, CHEMIA, LIV, 1, 2009

Dedicated to Professor Liviu Literat, at his 80th anniversary

HEAT INTEGRATION OF AN INDUSTRIAL FLUID CATALYTIC CRACKING PLANT

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ABSTRACT. The fluid catalytic cracking process represents the main conversion process in a refinery. The successful operation of the FCC unit determines the position on the market of the refinery. The objective of this work is to analyze the actual heat exchanger network (HEN) of an industrial fluid catalytic cracking plant (FCC) and, using real data provided by a refinery from Romania and Pinch technique, to improve it. ASPEN Plus was used to simulate the process. ASPEN HX-Net was used to generate the retrofitted designs of the HEN. The obtained results present the possibility to improve the actual heat exchanger distribution in the heat exchanger network and to save energy. Adding heat exchangers, re-piping, and improving the performance of some heat exchangers, it is possible to save energy from the actual heat exchanger network and to improve the process operation.

Keywords: *fluid catalytic cracking, heat exchanger network, optimization*

INTRODUCTION

The fluid catalytic cracking process (FCC) is the process most common used in any modern oil refinery. The FCC unit consists of three distinct sections: the reactor-regenerator unit section including air blower and waste heat boiler, the main fractionator section including wet gas compressor and unsaturated gas plant section (Gascon). In order to improve its operation and to recover a certain quantity of energy, the FCC process must go through some structural changes (retrofitting). Retrofitting represents changes (new heat transfer area, re-piping, changing the heat exchangers place, etc) in the actual structure of the HEN in order to reduce the operation cost and in this way to increase the capital cost, indicating that there is a trade-off between the operational and capital costs.

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The method most used for energy integration is Pinch Analysis. This technique is the simplest, easy to use, with immediate results and demonstrates its efficiency and applicability in many industrial saving energy problems. In addition, heat integration reduces site utility costs and capital costs. The savings made applying this technique came up to the 20-30% comparative with classical process design (B. Linnhoff, 1997).

A rigorous analysis of a FCC plant for energy saving was made by B. A. Al-Riyami et al., 2001. The HEN included the feed preheating, main fractionation and gas concentration section. The system was simulated using HySys.

The aims of our research were to analyze the actual heat exchanger network (HEN) of an FCC industrial plant using real process data (ex. flow streams, temperatures, transfer areas etc.) and to improve its operation from the economical point of view, using Pinch Analysis.

The FCC plant was already integrated in the past, during the time there were some changes in its operation (different raw materials, no production of heavy gasoline, different flow streams etc.). Constrained by the new type of operation and changes appeared in the design, a retrofit was realized trying not to affect the conversion process.

RESULTS AND DISCUSSION

Analyzing the existing HEN

The investigation of the actual HEN and the determination of the minimum duty of heating and cooling utilities have been done. The system was simulated in ASPEN Plus with the real process data collected from a Romanian refinery (UOP Fluid Catalytic Cracking process).

The scheme of the FCC unit which was implemented in Aspen Plus may be seen in the Figure 1.

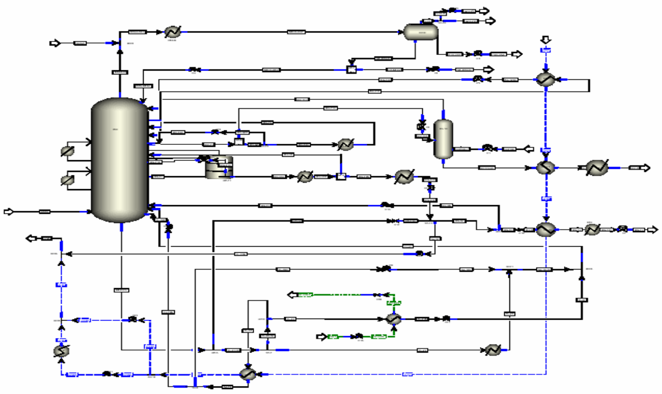


Figure 1. Flow diagram of FCC process.

In this study was realized the inventory of the heating and cooling sources. The data extracted from the simulation results using ASPEN HX-Net may be seen in Table 1. The table comprises 10 hot streams and 4 cold streams.

Table 1. Hot and Cold Streams Extracted from Simulation

Streams	Type	Supply Temp. [C]	Target Temp. [C]	CP [kW/C]	HTC [kW/C-m2]	Enthalpy [kW]
SL-20-21	Hot	393.6	254	35.95	0.15	5018.0
SL-22-23	Hot	393.6	238	74.94	0.12	11660.3
SL-18-19:23	Hot	393.6	234.4	37.41	0.12	5956.1
MG-9:MG-10	Hot	334.7	60	17.89	0.15	4914.8
MG-41A:MG-41B	Hot	250.4	224	102.39	0.15	2703.0
MG-42B:MG-42D	Hot	224	177	5.85	0.12	275.1
MU-86A:MU-72	Hot	205.5	108.9	79.31	0.12	7661.8
MOT-USO:MU-83	Hot	177.2	60	9.64	0.2	1129.3
BG-111:BG-129	Hot	145.4	98	61.74	0.2	2926.7
BU-207:BENZ-OUT	Hot	66	43	342.60	0.15	7879.9
C-31:C-32	Cold	80	110.2	96.91	0.15	2926.7
C-32:C-33	Cold	110.2	114.5	96.86	0.15	416.5
C-33:C-34	Cold	114.5	143.2	96.94	0.15	2782.3
C-34:C-35	Cold	143.2	204.7	96.85	0.15	5956.1
C-35:C-36	Cold	204.7	293.8	96.82	0.15	8626.6
B1-GE12:B2GE12	Cold	172	187.6	747.46	0.25	11660.3
B1-GE11:B2GE11	Cold	172	176.1	659.27	0.2	2703.0
B1-GE9:B2GE9	Cold	105	112.7	995.04	0.2	7661.8
WFE3-FE23	Cold	100	200.7	49.83	0.5	5018.0

The raw material stream of the FCC process, mainly the heavy vacuum distillate stream from the vacuum distillation unit, is a cold stream that is been heated up to a temperature around 290 ^{0}C in 4 heat exchangers (streams: C-31:C-32, C-32:C-33, C-33:C-34, C-34:C-35 and 1 fire heater (stream C-35:C36).

The products stream from the riser is fractionated in the main column in the following streams: heavy diesel oil, light diesel oil, heavy gasoline, light gasoline and slurry.

The slurry stream separated on the bottom of the column has the highest temperature (393.6 ^{0}C). It provides energy to produce superheated steam (WFE3-FE23) and to heat up other process streams: the gasoline from Gascon and the raw material. The steam generation stream was considered as a process stream in order to keep the existing production of steam the same both before and after the retrofit. The steam is needed for the other processes from the refinery. In the Aspen Plus simulation slurry stream is splited in: SL-20-21, SL-22-23 and SL-18-19:23.

The cold gasoline streams from Gascon plant (B1-GE12:B2GE12, B1-GE11:B2GE11, B1-GE9:B2GE9) were considered to be process streams trying not to modify the process behavior and the consumption of cold utility of the FCC process. The light (MU-86A:MU-72, MOT-USO: MU-83) and heavy (MG-41A:MG-41B, MG-42B:MG-42D) diesel oil streams help to increase the temperature of the raw material and are cooled and sent to storage. Heavy diesel oil (BG-111: BG-129) in the actual operation of the FCC process it's not considered anymore as one of the main products. It is used only to heat up the raw material stream and then is reintroduced in the main column. The gasoline and gases stream from the top of the column (BU-207: BENZ-OUT) is sent to Gascon unit after a part of the gases are separated to the furnace.

Based on the data provided by the simulation and that have been presented in Table 1, the composite curves (Figure 2) and Grand composite curve (Figure 3) were generated.

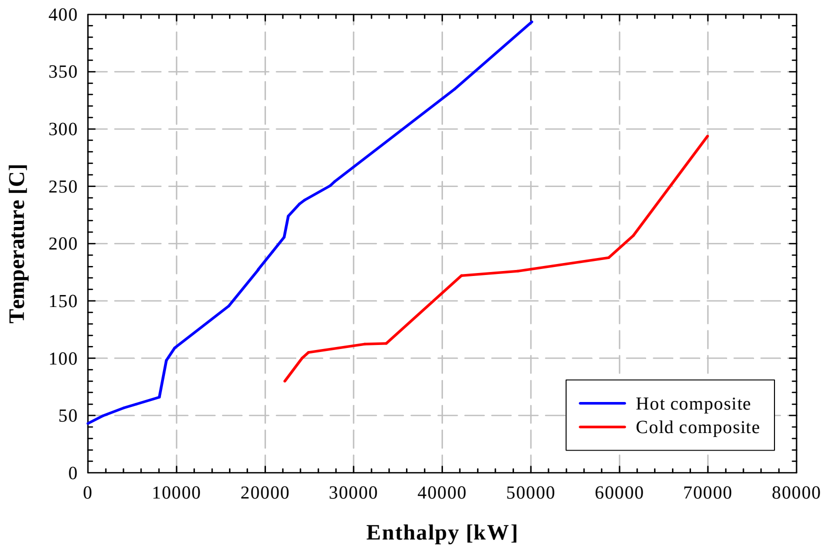


Figure 2. Composite Curves of the existing HEN.

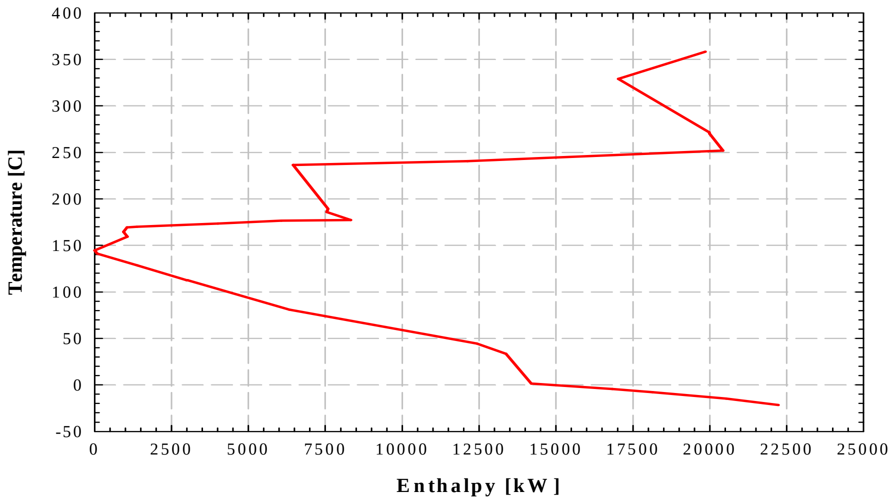


Figure 3. Grand Composite of the existing HEN.

The Grand composite curve shows that the pinch temperature of the process is 144.5^{0}C and from the composite curves it was discovered that the ΔT_{min} for the process is 129^{0}C and the duty of hot utility is 19858 kW and of cold utility is 22234.79 kW.

Table 2. Heat exchangers from the industrial process

Heat exchanger	Cost [$]	Simulation area [m2]	Real area [m2]	Duty [kW]
FE-21	271525.74	941.91	324	2926.69
FE-18	62073.63	81.15	113	2782.33
FE-9	0.00	0.00	18777	0.00
FE-4	52865.53	50.28	120	2132.50
FE-22	38003.33	8.44	7	275.09
FE-17	48050.00	35.39	248	416.46
FE-3	83867.74	163.15	76	4766.40
FE-23	39939.71	13.04	12.3	251.60
FE-6	106258.59	256.77	894	7879.95
GE-12	366717.43	1678.59	-	11660.34
FE-2	130758.34	367.28	111	5956.05
FE-10	73604.16	123.20	2776	712.84
GE-9	462658.57	1657.14	-	7661.77
GE-11	197879.39	596.48	-	2702.99

The simulation of industrial process provided 15 heat transfer units (excepting the fire heater) that are summarized in Table 2. The cold utilities used are cooling water (94%) and air (6%) with a total cooling need of 11000.38 kW. The only hot utility considered is the fuel (8626.6 kW).

The heat exchanger FE-9 present in the real process it is used only for cooling down the temperature of the gasoline stream (top of the column) when it increases above a fixed value. The heat exchangers GE-9, GE-11 and GE-12 are located in the Gascon plant and they have to remain unmodified.

Besides the heat exchangers summarized in Table 2, preheating train of the raw material contain another heat exchanger, FE-24, that is out of order and it wasn't considered in the simulation. It was designed to cool the heavy gasoline stream that goes to the storage but this product is not produced anymore.

The existing heat exchanger network design was generated by Aspen HX-Net (Figure 4). The heat transfer marked with blue dots represents the heat exchangers with cold utilities, the red dots represent a heat exchanger with hot utility and the grey dots represent process to process heat exchangers.

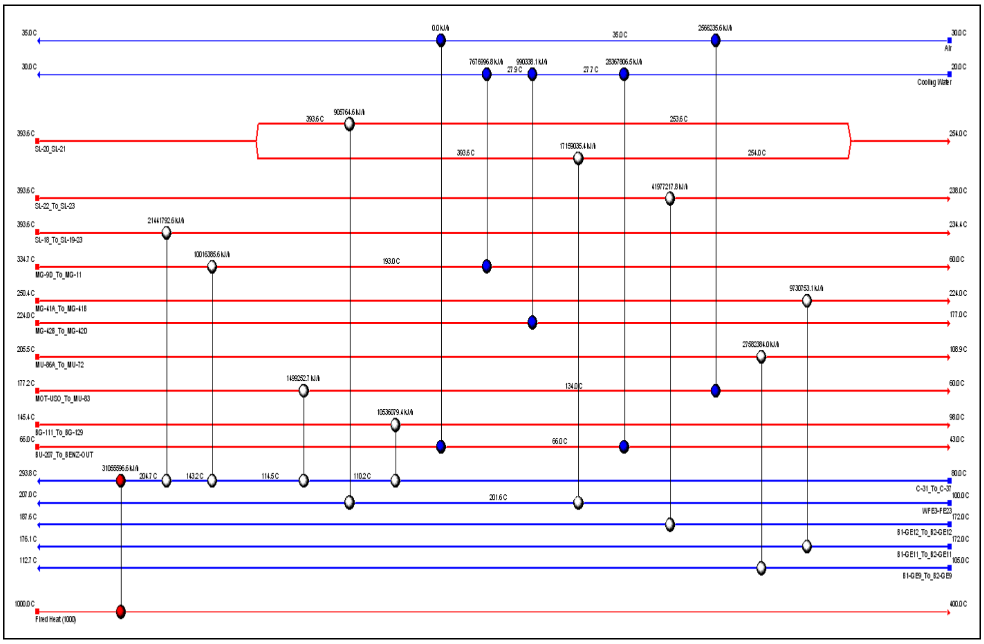


Figure 4. Existing Heat Exchanger Network.

Improving the existing HEN

In order to improve the real heat exchanger network the optimization of the total cost of FCC process was done. The total cost as a function of ΔT_{min} is represented in Figure 5. It can be seen that the minimum cost is achieved in a range of ΔT_{min}=8.5 to 12^{0}C; and as a conservative approach the optimum minimum approach temperature for the retrofit target is ΔT_{min}=12^{0}C because operating with a ΔT_{min} less than 10 ^{0}C should be avoided [4].

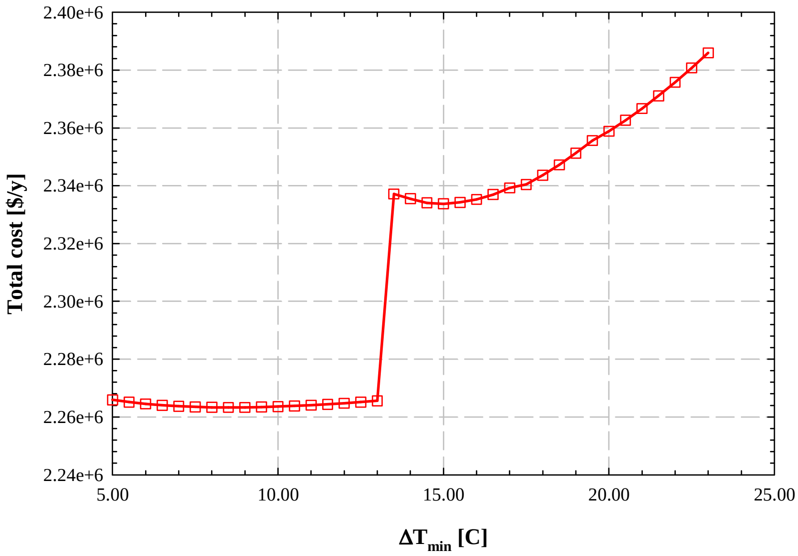


Figure 5. Total cost vs. minimum ΔT.

Considering that the actual HEN is operated with ΔT_{min}=129^{0}C, decreasing it to 12^{0}C it is possible to improve the actual heat exchanger distribution for saving energy of 13553 kW.

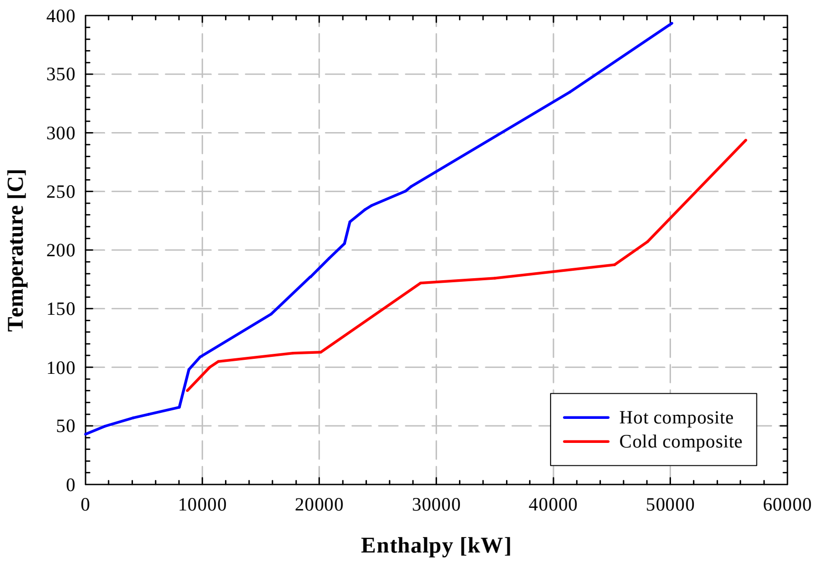


Figure 6. Composite curves with ΔT_{min}=12^{0}C.

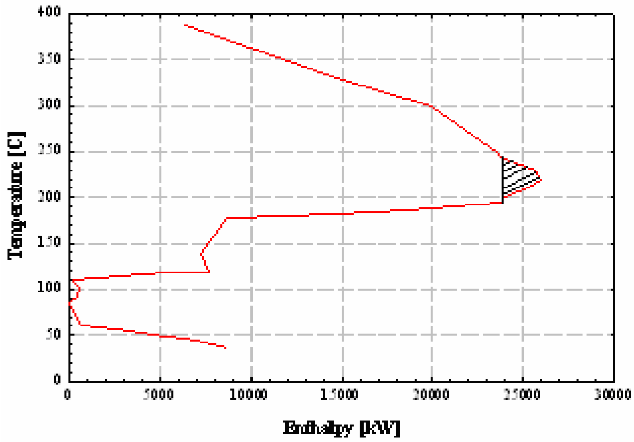


Figure 7. Grand Composite curve with ΔT_{min}=12^{0}C

The new composite curves, generated in Figure 6 and Figure7, show that the pinch temperature has been reduced from 144.5 ^{0}C to 88 ^{0}C and the minimum need of heating and cooling is reduced to 6325.92 kW and 8701.28 kW respectively. In conclusion, reducing the ΔT_{min} reduces the heating and cooling needs approximately with 32% and 39% respectively. Also it can be observed in Grand Composite curve that there are some pockets of extra energy that may be saved.

Table 3 presents the comparison of the necessary of cooling and heating needs in those two cases considered: ΔT_{min}=129 ^{0}C and ΔT_{min}=12 ^{0}C. These results were compared against the Grand Composite curve (Figure 8).

Table 3. Saving energy through reduction of ΔT_{min}

		ΔTmin [^{0}C]		Reduce
		129	12	[%]
Heating	[kW]	19859.00	6325.92	68.15
Cooling	[kW]	22234.36	8701.28	60.87

In the new HEN, generated with Aspen HX-Net, there is not process-to-process heat exchange that crosses the pinch temperature. This is an improvement compared to the initial design extracted from the simulation.

In order to improve the HEN other designs were generated and analyzed. The only change considered in those designs is the distribution of the heat exchangers. The designs were compared in terms of their operation costs and efficiency. In all the designs the stream corresponding to steam generation was consider as a process stream. Five designs were proposed and have been used the economic model recommended in [1] and by ASPEN HX-Net.

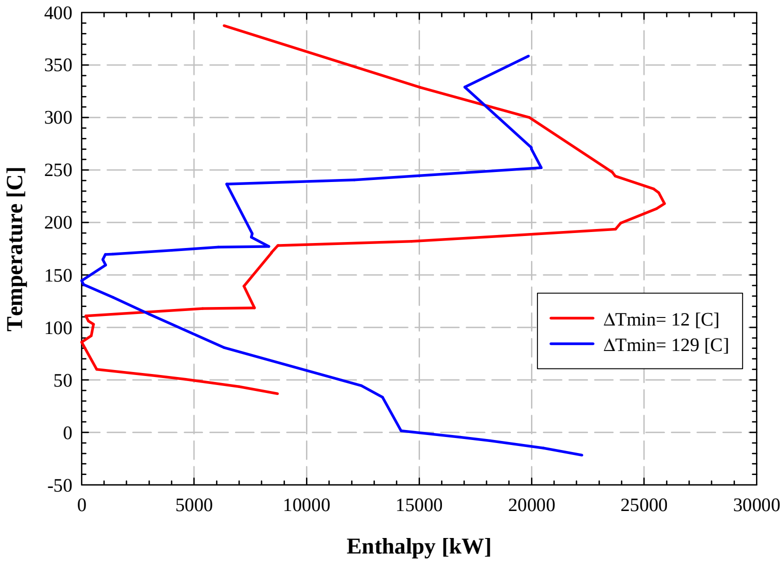


Figure 8. Grand Composite curves comparison.

The designs used present the following conditions:

Design A:

- The order of the heat exchangers are changed optimizing the production of steam;
- The total area of the HEN was increased;
- The operating cost was reduced.

Design B:

- Addition of a fire heater to heat the cold stream;
- The heating and cooling needs are decreased;
- The operating cost and the total cost are reduced.

Design C:

- The split of slurry stream was taken out;
- The number of heat exchangers was reduced;
- The operation and the capital costs have been increased;
- The cooling need was the same as in the base case;

The total area was increased.

Design D:

- The number of heat exchangers that are used to heat up the raw material were increased;
- The total area of the heat exchangers was increased;
- The operating cost and the total cost increased.

Design E:

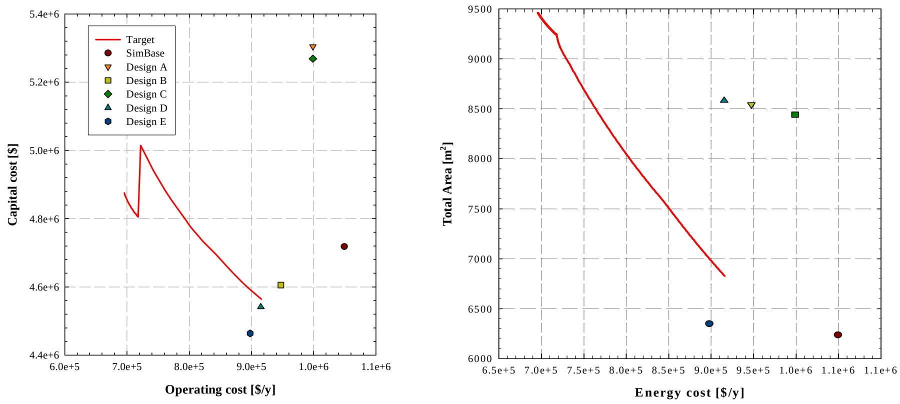
- A part of the hot stream “heavy diesel oil” was re-piped to produce steam;
- The heating and cooling needs were decreased;
- The operating, capital, and total costs were reduced.

The characteristics (total cost, transfer area, etc.) of the designs obtained are compared in the Table 4.

Table 4. Comparison among designs evaluated

	Total cost [$/y]	Area [m2]	Heating [kW]	Cooling [kW]	Operating cost [$/y]
SimulationBaseCase	2569201.45	6238.39	8626.55	11000.38	1049460.81
Design A	2707323.90	8443.29	8621.23	11000.38	998785.53
Design B	2430791.22	8542.85	8309.79	10689.08	947392.96
Design C	2695805.34	8441.96	8621.23	11000.38	998785.53
Design D	2377950.54	8581.62	8033.84	10413.99	915249.06
Design E	2335706.83	6350.65	7325.39	9701.64	897860.72

The performance of the considered designs, with respect to the ideal target, was evaluated through the alpha plot, the closest the existing HEN is to the ideal curve in an energy area plot the better the performance. In Figure 9a may be seen that there are at least three designs that could have a better performance than the simulation base case (e.g., design B, D and E).



a) b)

Figure 9. a) Performance of the designs. b) Efficiency of the proposed designs respect to the ideal.

Figure 9b shows the efficiency of the designs considered. The closest to the ideal efficiency are the design E and the design considered in the simulation base case, indicating that those designs are using efficiently the heat transfer area. The designs A, B, C and D are far from the ideal performance.

It could be advantageous from the economical point of view to change the existing HEN with design E (Figure 10) that has lower energy consumption, capital and operational costs than the existing HEN. Considering the results from Table 4, total costs are decreased with approximately 9% and there is an energy saving of 15% of heating and 12% of cooling. However, the performance of this design needs to be evaluated through a simulation implemented in Aspen Plus or Aspen Dynamics to see if it is the best choice in all conditions (economics, dynamic behavior, controllability etc.).

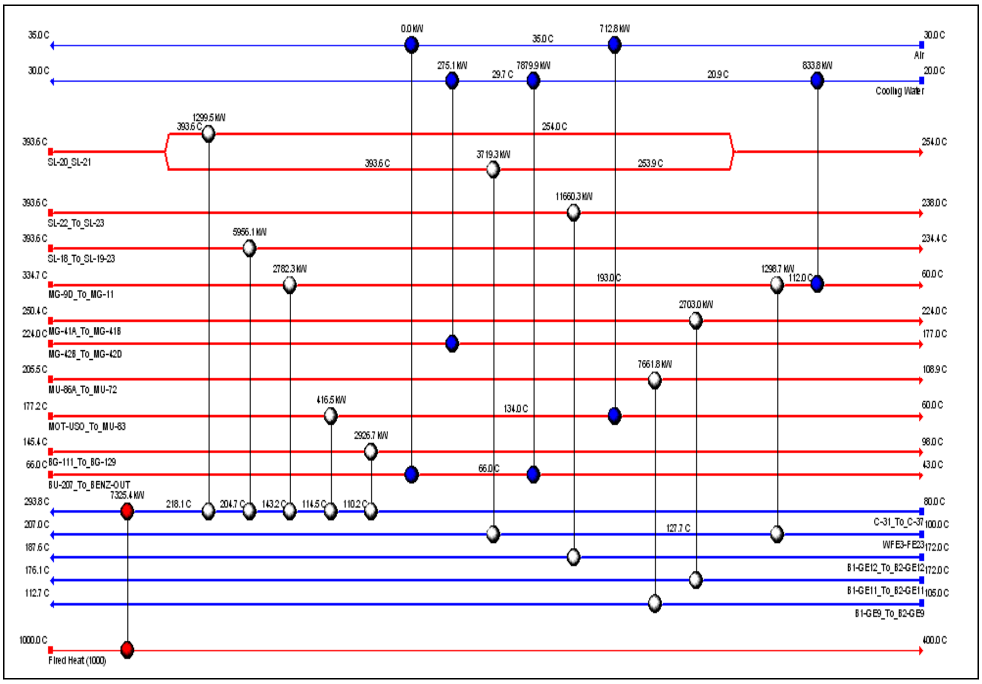


Figure 10. Heat exchanger network – Design E.

CONCLUSIONS

The fluid catalytic cracking is a dominant process in oil refineries and there has been a continuous effort to improve the efficiency and yield of the unit over the years.

The results of the present retrofit study confirmed that it is possible to save energy from the actual heat exchanger network. The improvement comprises adding heat exchangers, re-piping, and improving the performance of some heat exchangers. The closest to the ideal efficiency is the design E because it uses efficiently the heat transfer area and it is the best design comparative with the existing industrial HEN. In the real HEN there are process-to-process heat exchangers that cross the pinch temperature. Total costs are decreased with approximately 9% and there is an energy saving of 15% of heating and 12% of cooling.

No drastic changes have been suggested for the existing HEN, the new design was done trying not to modify the process-to-process heat exchangers, assuring that the process would not be affected.

Significant quantities of hot and cold utilities (water, gas, etc.) are saved by reducing the heating and cooling needs in the FCC plant. This is an important step in conserving and recycling the natural resources.

This optimization of the HEN in terms of the economical point of view gives a starting point to continue with the improvement of the industrial process. Future work will analyze the generated designs in terms of dynamic behavior and controllability.

ACKNOWLEDGMENTS

The authors are thankful for the financial support from the Romanian Ministry of Education, Research and Youth through the research grant PD-CEEX “Operation of the non-stationary catalytic depollution and thermally integrated processes using techniques of advanced process control“.

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