Simulation and Energy Conservation in Natural Gas Processing Plants

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Abstract:

The present work aims at investigating opportunities for energy conservation in Western Desert Gas Complex (WDGC) through modification of the heat exchanger train. Process simulation of the plant under winter and summer conditions was performed using Hysis steady state simulation program. This step was necessary to furnish stream property data requested for heat analysis as well as condensers and reboilers duties, a usually missing information in chemical processing plants. Minimum heating and cooling energy requirements were calculated for different values of minimum approach temperature (ΔT min) by two methods; the pinch method and the linear programming method. The aim was reaching optimum design of (HEN) achieving the least annualized total cost. Finally the heat exchanger network was designed using the Pinch Design Technology, PDT. Modifications to the existing network were proposed to reach optimum HEN with the least alterations.

Key Words:

Natural Gas Processing, Heat Exchangers Network synthesis, Energy Conservation in Natural Gas Processing Plants.

1. Introduction:

In the past three decades, extensive efforts have been made in the fields of energy integration and energy recovery technologies because of the steadily increasing energy cost and CO2 discharge concern. A heat recovery system consisting of a set of heat exchangers can be treated as a heat exchanger network (HEN), which is widely used in process industries such as gas processing and petrochemical industries, to exchange heat energy among several process streams with different supply temperatures.

By the use of HENs, a large amount of utility costs such as the costs of steam and cooling water, as well as the costs of heaters and coolers, can be saved. However, it would increase the investment for the additional heat exchangers, and therefore a balance between the capital costs and running costs should be established. The task of the Heat Exchangers Network Synthesis, HENS, is to find a HEN which has the minimum total annualized cost. Because of its significant benefits in saving energy consumption and equipment costs, HENS has been considered as one of the most important research subjects in process engineering [1].

The well-known procedures of HEN synthesis are the pinch method proposed by Linnhoff [2—5], the mathematical programming procedures developed by Grossmann and his coworkers[6—8], and the stochastic or heuristic algorithms such as genetic algorithm[9,10], genetic/simulated annealing algorithm[11—15], and Tabu search procedure[16].

Due to the great benefits which can be realized by applying heat exchangers networks synthesis for industrial plants, we have chosen a natural gas processing unit of Western Desert Gas Complex, WDGC, trying to minimize the consumption of utilities with the least added capital cost.

2. Western Desert Gas Complex (WDGC) Fig (1):

The purpose of the **W**estern **D**esert **G**as **C**omplex [17] is to recover the C_2 / C_3 as well as LPG products from a natural gas stream by condensation at low temperature. In order to achieve this target, the use of a throttling valve and an expander system was necessary to condense the C_2 / C_3 present in the feed gas. This scheme is interesting in that the cooling effect is generated by depressurization of the gas. The pressure drop of the gas to be treated is limited to the minimum to ensure the C_2 / C_3 recovery. As a consequence, it is necessary to recompress the residue sales gas after treatment. The gas separation process is composed of a series of fractionation towers to separate methane, ethane and propane respectively and a final tower that separates LPG and condensate as top and bottom products.

The feed gas is split into two identical streams feeding identical processing trains. Each train is composed of a molecular sieves package to remove water, gas-gas exchanger, an expansion valve, a turbo expander, and a demethanizer. The overhead product from the demethanizer (sales gas) is used to cool the feed gas while the liquid product of the demethanizer columns of the two trains are combined for further separation of the product streams as shown in Fig(1). A heat exchanger network is available for heat exchange between the hot and cold streams.

3. Process Simulation for WDGC:

Process simulation for WDGC existing plant was necessary to furnish streams data required for energy analysis. Simulation module of WDGC was formulated and executed using HYSYS simulation program version 3.2.which is designed to serve many processing industries especially those of Oil & Gas. Simulation was performed taking into consideration:

1- The actual specifications of feed and products streams.

2- Using the same design parameters of all equipments as in actual case.

3-Using Peng-Robinson equation of state for the estimation of physical property data.

The reliability of simulation was first examined by comparing the actual data with the data of simulation. Mass balance and enthalpy of the process streams are the most important results of simulation which are required for stream analysis and therefore for energy analysis.

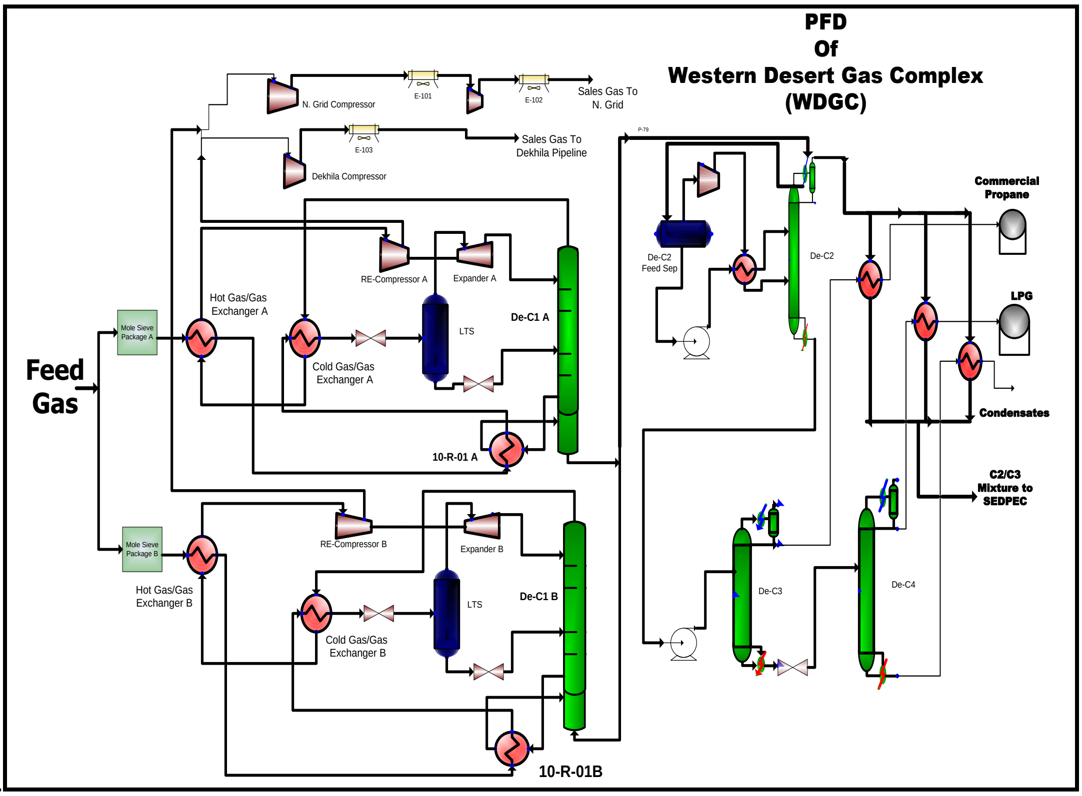
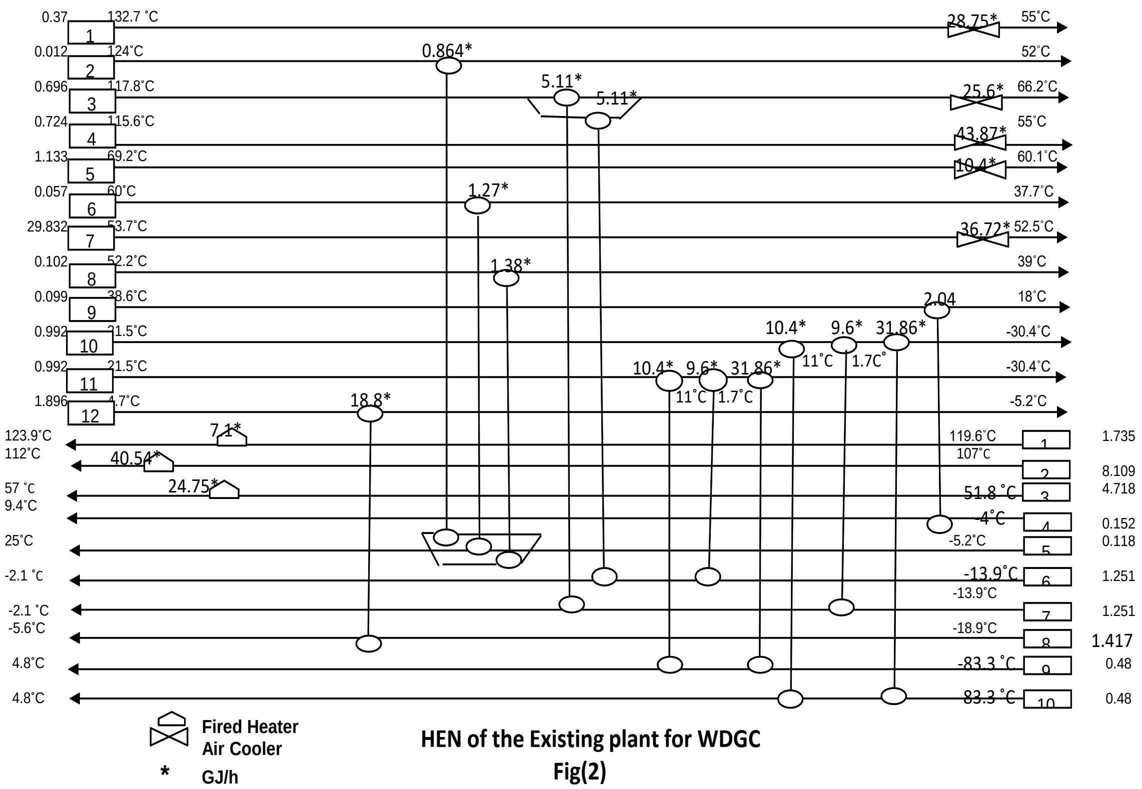


Figure (1) Flow Sheet of WDGC (existing design)

4. Energy Analysis for Western Desert Gas Complex:

We can summarize the energy analysis steps in the following points:

- The first step is dividing the process streams into two groups of hot and cold streams with their specification of supply temperatures, target temperatures and heat capacity flow rates (see Table [1])
- The second step is drawing the existing heat exchangers network on the grid diagram and calculating the actual consumption of hot and cold utilities as shown in Figure (2).
- The third step is defining the minimum (target) consumption of hot and cold utilities at different values of minimum temperature approach (ΔTmin).
- Design the heat exchangers network (HEN) corresponding to each ΔT min taking into consideration the rules of energy recovery according to the pinch design technology (PDT) so as to achieve the minimum target utilities in each case.
- By comparing the different designs of HEN w.r.t. operating cost, capital cost, number of units, flexibility and controllability, we can define the optimum one which achieves minimum overall annualized cost.
- Revamping the existing HEN can take place by adding new units or modifying the existing matching of HEN so as to reach the optimum or nearly optimum with the least cost.



HEN of the Existing plant for WDGC
Fig(2)

Table[1] Streams Data of Western Desert Gas Complex (WDGC)

TAG	Stream Name	Stream No.	T in , ºC (Supply Temp.)	T out , ºC (Target Temp.)	Exchangers duty , M Kcal/hr	Exchangers duty , GJ/hr	Heat Capacity rate ,GJ/hr.ºC
H1	Discharge of Dekhila Comp	S6	132.7	55.0	6.87	28.74	0.370
H2	Liq from De-C4	22B	124.0	52.0	0.21	0.86	0.012
H3	Discharge of 1st stage residue gas Comp	S2	117.8	66.2	8.58	35.90	0.696
H4	Discharge of 2nd stage residue gas Comp	S4	115.6	55.0	10.48	43.85	0.724
H5	Gas to De-C4 Condenser	Gas to De-C4 Condenser	69.2	60.1	2.48	10.38	1.133
H6	Gas from De-C4	20	60.0	37.7	0.31	1.28	0.057
H7	Gas to De-C3 Condenser	Gas to De-C3 Condenser	53.7	52.5	8.78	36.71	29.849
H8	Gas from De-C3	17	52.5	39.0	0.33	1.37	0.102
H9	Discharge of De-C2 feed comp	12A	38.6	18.0	0.49	2.03	0.099
H10	Feed Gas to train A	2A	21.5	-30.4	12.31	51.51	0.992
H11	Feed Gas to train B	2B	21.5	-30.4	12.31	51.51	0.992
H12	Gas to De-C2 Condenser	De-C2 Condenser stream	4.7	-5.2	4.49	18.79	1.896
C1	Liq to De-C4 Reb.	De-C4 reboiler stream	119.8	123.9	1.70	7.11	1.735
C2	Liq to De-C3 Reb.	De-C3 reboiler stream	107.0	112.0	9.69	40.54	8.109
C3	Liq to De-C2 Reb.	De-C2 reboiler stream	51.8	57.0	5.92	24.77	4.718
C4	Liq from De-Ce OVHD acum	13	-4.0	9.4	0.49	2.03	0.152
C5	C2/ C3 mix.	14	-5.2	25.0	0.85	3.56	0.118
C6	Liq to De-C1 A reb.	De-C1 reboiler stream A	-13.9	-2.1	3.52	14.73	1.251
C7	Liq to De-C1 B reb.	De-C1 reboiler stream B	-13.9	-2.1	3.52	14.73	1.251
C8	Liq from De-C1 to De-C2 Condenser	11A	-18.9	-5.6	4.49	18.79	1.417
C9	Gas from De-C1 A	5A1	-83.3	4.8	10.01	41.88	0.48
C10	Gas from De-C1 B	5B1	-83.3	4.8	10.01	41.88	0.48

4.1. Prediction of Minimum Utilities for WDGC:

The first step in HEN design is defining the minimum utilities required (energy targeting). Knowing the streams specifications namely, supply and target temperatures and heat capacity flow rates, two approaches can be tackled to find minimum hot and cold utilities. These are the problem table algorithm of the pinch design method and the mathematical formulation with linear programming.

4.1.1. The Problem Table Algorithm:

Linnhoff et al. (4) developed the problem table algorithm as a mathematical tool to replace the graphical grand composite curves method for predicting the pinch point and hence minimum utilities prior to design for any HEN.

4.1.2. Mathematical Formulation with linear programming [LP]:

In a previous publication [18] we developed a software program [Automatic Prediction of Minimum Utilities, AMU] which applies the linear programming with transshipment model [7]]. The program input data are stream and utility properties and the proposed ΔTmin. The program partitions the temperatures range of the case into intervals. Then it automatically formulates the energy balance equation for each interval with objective function of minimizing utilities. These equations can be solved by standard mathematical optimization software [LINDO] to predict minimum utilities and define the pinch point.

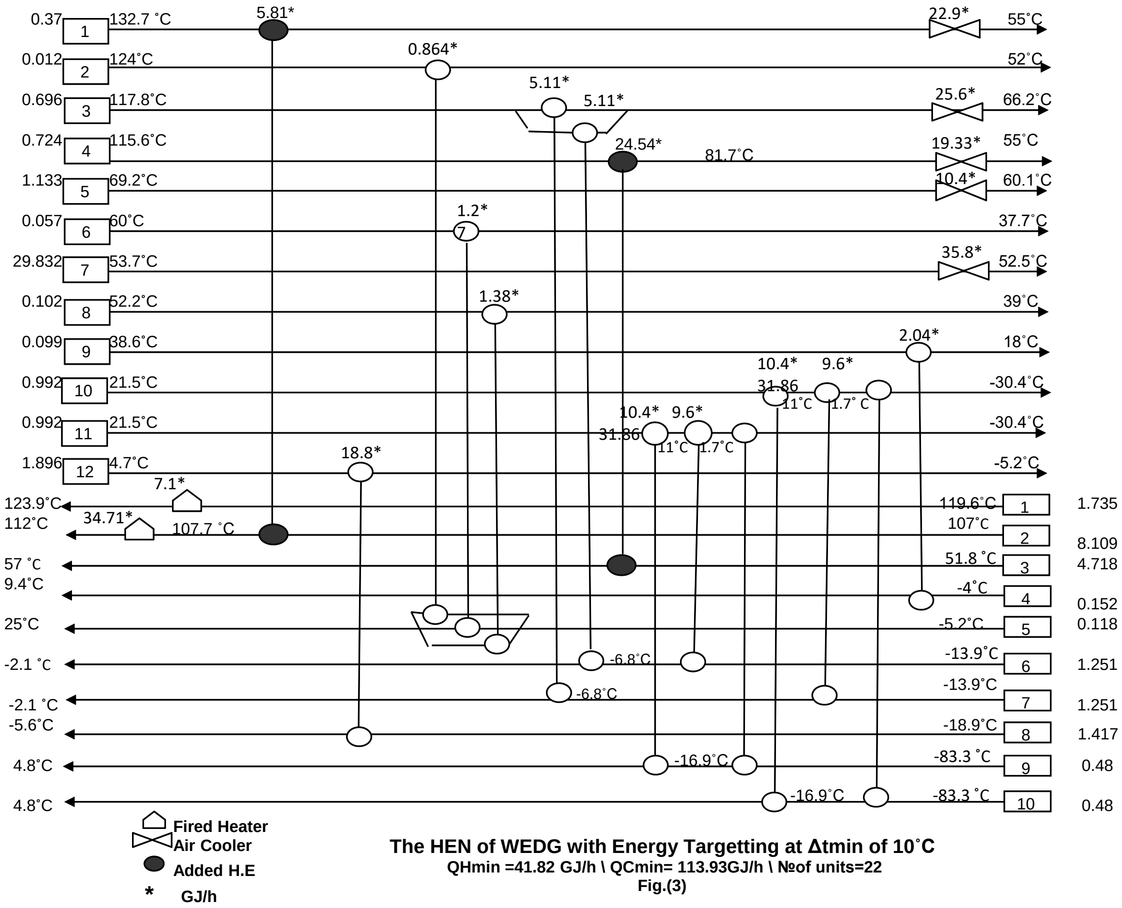
4.2. Energy Targeting for WDGC:

The above mentioned two methods have been applied on the streams data of WDGC Table (1) at different values of –ΔTmin (10, 15, 20, and 25). Prediction of minimum utilities and the pinch points by both methods are compared in Table [2]. The results of the two techniques are very close which confirms the accuracy of the developed software.

Table [2]: Comparison between Results of [LP] & [PDM] for WDGC at different values of ΔTmin:

ΔTmin °C	Linear Programming method				Problem Table Method			
	Thp °C	Tcp °C	QHmin GJh^{-1}	QCmin GJh^{-1}	Thp °C	Tcp °C	QHmin GJh^{-1}	QCmin GJh^{-1}
10	117	107	41.2	114.14	117	107	41.21	113.23
15	122	107	43.67	115.57	122	107	43.67	115.69
20	127	107	45.55	117.79	127	107	45.55	117.57
25	133	107	47.4	119.8	132	107	47.4	119.42

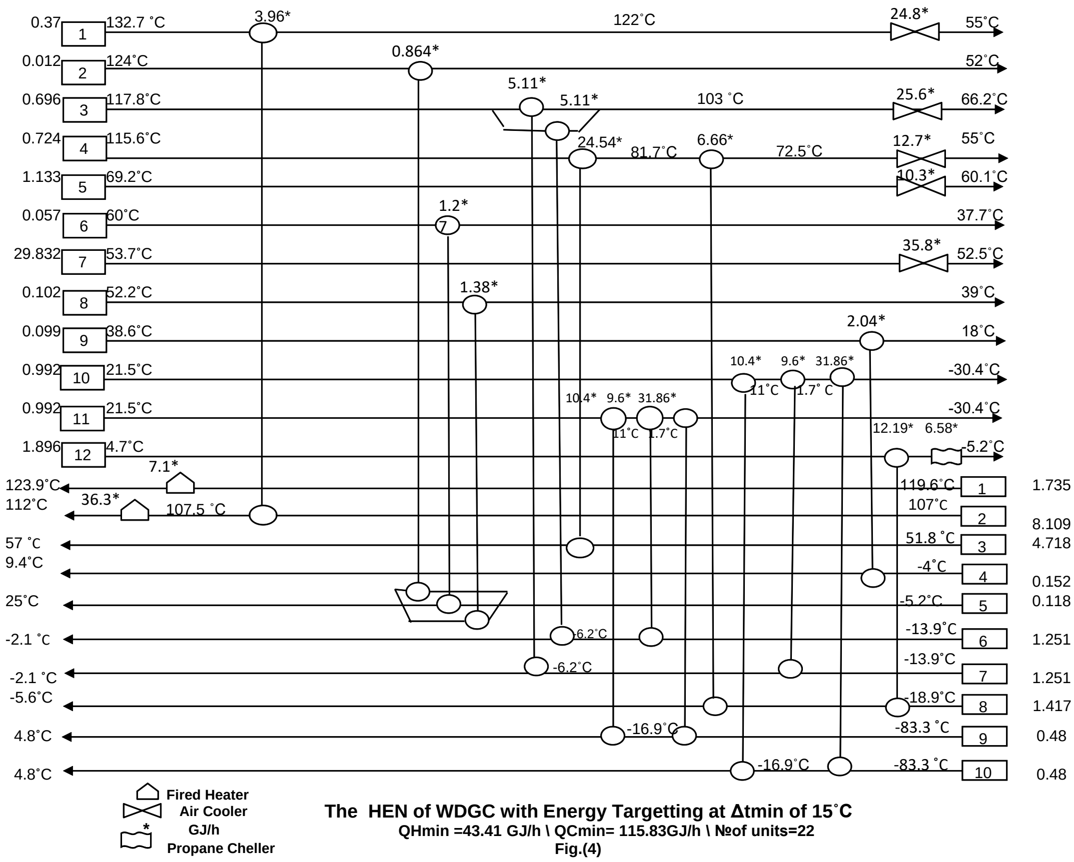
The second step is the synthesis of heat exchangers network (HEN) for WDGC at different values of. ΔTmin by applying the pinch design rules (4).



The HEN of WEDG with Energy Targetting at Δtmin of 10˚C

QHmin =41.82 GJ/h \ QCmin= 113.93GJ/h \ №of units=22

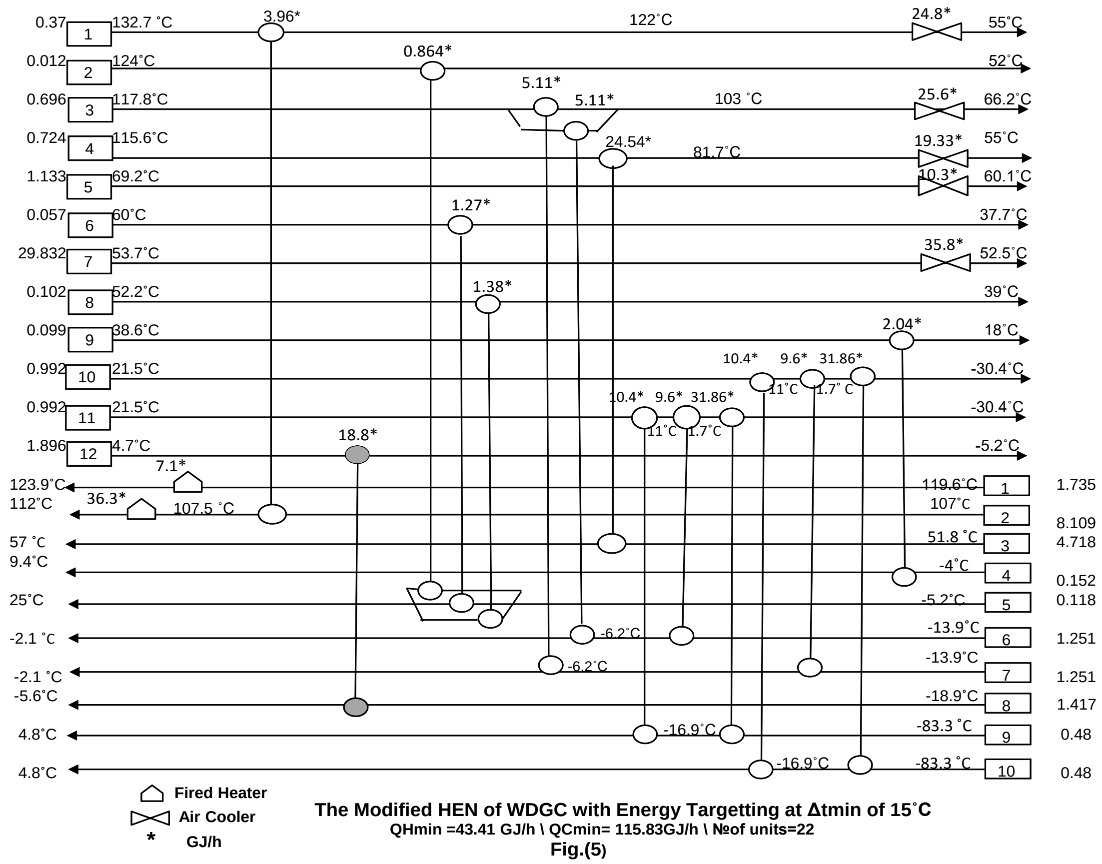
Fig.(3)



The HEN of WDGC with Energy Targetting at Δtmin of 15˚C

QHmin =43.41 GJ/h \ QCmin= 115.83GJ/h \ №of units=22

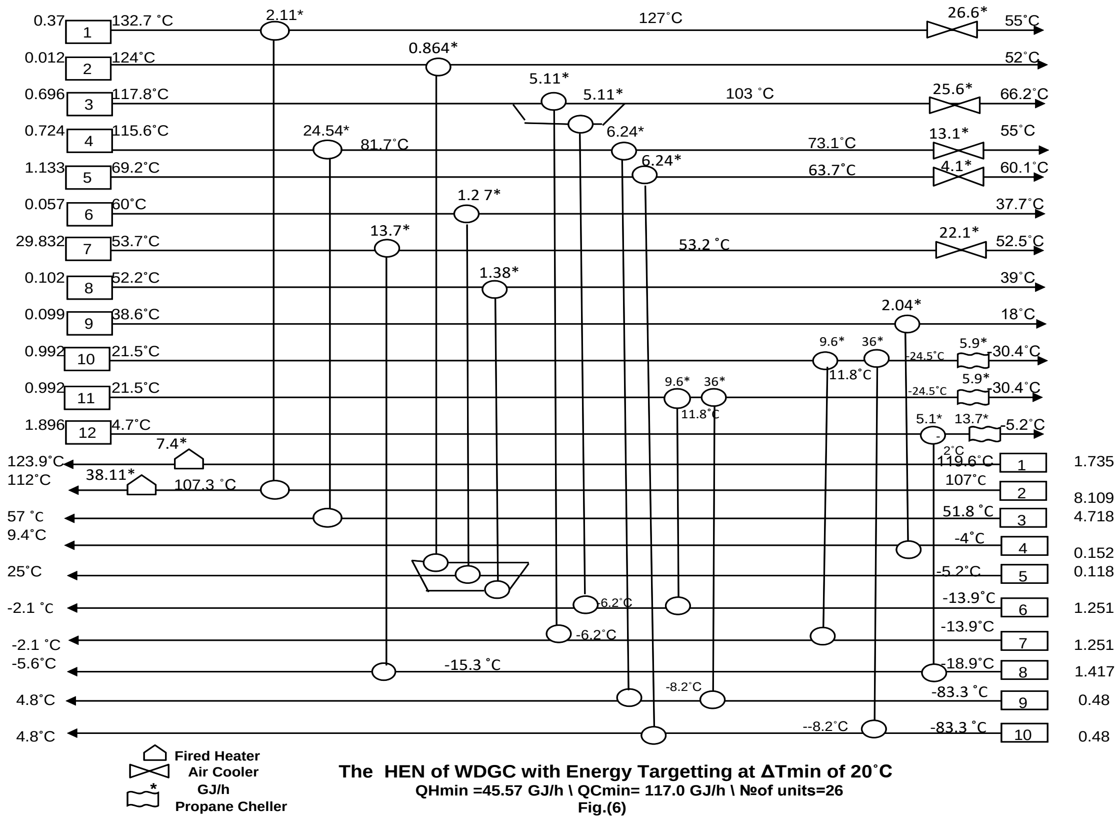
Fig.(4)



The Modified HEN of WDGC with Energy Targetting at ΔTmin of 15˚C

QHmin =43.41 GJ/h \ QCmin= 115.83GJ/h \ №of units=22

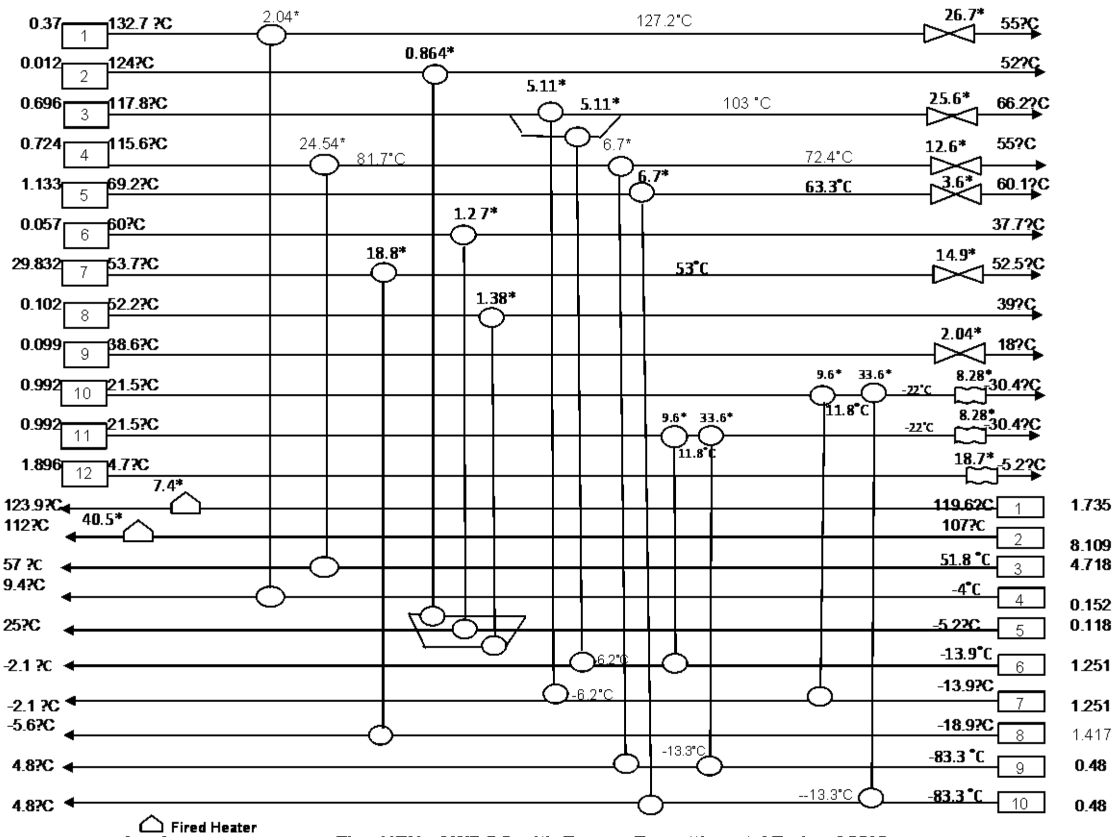
Fig.(5)



The HEN of WDGC with Energy Targetting at ΔTmin of 20˚C

QHmin =45.57 GJ/h \ QCmin= 117.0 GJ/h \ №of units=26

Fig.(6)



The HEN of WDGC with Energy Targetting at ΔTmin of 25˚C
QHmin =47.9 GJ/h \ QCmin= 120.7 GJ/h \ №of units=25
Fig.(7)

5. Heat Exchangers Network Synthesis, HENS for WDGC:

Following PDM rules, the different HENs designed corresponding to different ΔTs min are shown in Figs. 3 to 7.

For ΔT min = 10 ^oC **(**Fig. 3) HEN design is very similar to the existing WDGC HEN Fig. (2). The only difference is that the new design uses two more new heat exchangers (shaded) that result in a complete elimination of a fired heater and a reduction in both heating and cooling loads.

For ΔTmin= 15 ^oC the same fired heater can be eliminated but a propane chiller would be needed on stream No. 12 (Fig.4). If, however, ΔTmin is relaxed at the exchanger between hot stream No. 12 and cold stream No. 8, the propane chiller can be eliminated (Fig.5). In both cases the target utility loads can be achieved which is naturally above the value for ΔTmin = 10 ^oC.

As ΔTmin is increased to 20 ^oC and 25 ^oC the target utilities also increase and the number of propane chillers requested to reach the target low temperatures increase Figures 6, 7.

5.1. Comparison between the Different Designs of HEN for WDGC:

To find the optimum HEN design which realizes minimum annualized total cost, it is required to estimate both of operating and capital costs for each case.

5.1.1. Capital cost:

The capital cost for stainless steel heat exchangers can be estimated by the equation [19]:

Cost of H.E [$] = 30800+1644 $A^{0.81}$

Where:

A = area of heat exchanger in m^2

Exchanger cost has to be corrected to the year (2007-2008)

Thus cost @ (2007-2008) = cost@ (1990) x CI (2007-2008)/ CI (1990)

Plant Cost Index [20] of (2007-2008) = 600

Plant Cost Index [20] of (1990) = 360

Studying offers to WDGC for fired heaters, air coolers and propane chillers in 200**7,** their average price can be estimated as follows:

Fired Heater price / m^2= 5128 \$/m^2

Air cooler price / m^2 = 989 \$/m^2

Propane Chiller price = 2,687,528 \$/$MMkcalh^{-1}$

5.1.2. Operating Cost can be estimated as follows:

Based on an average price for electricity of 0.18$/kWh and natural gas price of 2.65$/$10^6$BTU and data supplied by WDGC on performance of air coolers, fired heaters, and propane chillers utility cost can be estimated as follows:

-Air coolers; The cost of GJ = 9.0038 $/day

-Fired Heaters; The cost of GJ = 2.516 $/h

-Propane Chillers; The cost of GJ = 27.713 $/day

5.1.3. Annualized Total Cost:

Assuming that the life time for HEN equipment = 6 years (19) then,

Annualized total Cost = Capital Cost/6+Operating Cost/y

The different cost items discussed above have been calculated for each HEN and a comparison of results is shown in Fig. (8).

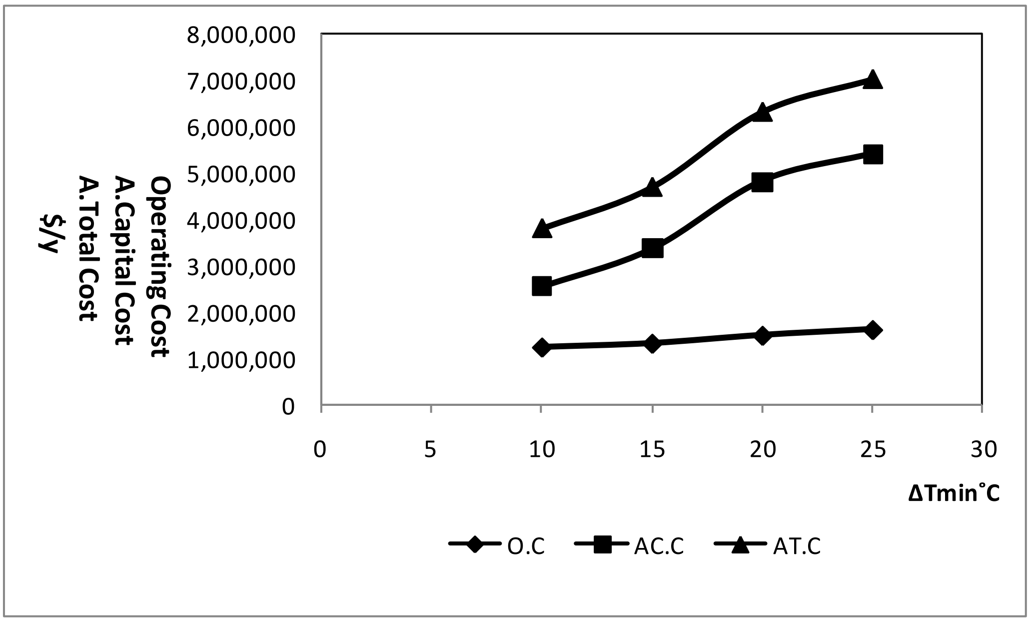


Fig. (8) Relation between ∆Tmin and Operating, Annualized Capital, &Annualized Total Costs

6. The Optimum Design of HEN:

6.1. Grass Root Design:

If we consider seeking the optimum grass root design for WDGC, then the different cost items are compared in Fig. (8). Details of design parameters and the costs are shown in Table [3] where data calculated for existing design is included for comparison. It is clear that the minimum overall annualized cost corresponds to ∆Tmin of 10˚C. The design of HEN at this ∆Tmin is presented in Fig.(3).
The optimum design consumes *41.82*GJh^{-1} of hot utility as compared to *72.4* GJh^{-1} for the existing design thus causing *42.2%* savings. Similarly savings in the cold utility amounts to *21.6%*. Although the number of units is *22* for the optimum design as compared to *21* for the existing design the capital cost of the former is less than that of the latter. The reduction in capital cost is affected, mainly due to reduction of fired heaters area. The net result is saving in the annualized total cost that reaches to ***1,088,379*** *$/y.*

6.2. Revamp of the existing design:

As mentioned above PDM design at ∆Tmin =10^{o}C is very close to the existing WDGC HEN design. Referring to Figs. (2, 3) only two exchangers are added while one fired heater is eliminated. The first H.E with a load of *5.81* GJh^{-1} between hot stream (H_1) and cold stream (C_2).The second H.E with a load of *24.54 GJh^{-1}* between hot stream (H_4) and cold stream (C_3)

The economic analysis of the revamped design compared to the existing one is presented in Table [4].

Table [3]: Comparison between networks specifications at different ΔTmin:

HEN / Network.Spec.	HEN of ΔTmin 10˚C	HEN of ΔTmin 15˚C	HEN of ΔTmin 15˚C #	HEN of ΔTmin 20˚C	HEN of ΔTmin 25˚C	Existing HEN
№ of Units	22	24	22	26	25	21
Load of Heaters GJ/h	41.82	43.41	43.41	45.57	47.9	72.65
Area of Heaters m^2	1269.5	1298.7	1298.7	1331.2	1374.1	1704.1
Capital Cost of Heaters $/y	1,085,532	1,109,385	1,109,385	1,137,138,	1,174,398	1,456,438
Load of Coolers GJ/h	113.93	115.83	115.83	117.0	120.7	145.3
Area of Coolers m^2	3252.3	3124.3	3280.4	2226.2	1729.2	3902.5
Capital Cost of Coolers $/y	536,083	520,511,	540,724	366,948	285,022	643,259
Load of Propane Chiller GJ/h	_	6.58	-	25.5	35.3	_
Capital Cost of Propane Chiller $/y	_	833,333	_	2,666,666	3,333,333	_
Operating Cost $/y	1,242,871	1,325,392	1,282,463	1,498,779	1,623,980	1,988,145
Area of H.E m^2	5134.1	4750.8	5084.4	3120.3	2664.7	4505.8
Capital Cost of H.E $/y	874,139	820,295	845,494	628,729	545,366	738,543
Total Capital Cost $/y	2,495,754	3,283,524	2,495,603	4,799,482	5,338,119	2,838,240
Overall Cost $/y	3,738,625	4,608 ,916	3,778,006	6,298,261	6,962,099	4,826,385

Table [4] Economic Analysis of the Revamped HEN:

	Existing plant	Optimum HEN
QH(hot utility) GJ/h	72.4	41.82
QC(cold utility) GJ/h	145.35	113.93
%Saving of QH	–	42.2%
%Saving of QC	–	21.6%
Saving of hot utility $/y	–	646,290
Saving of cold utility $/y	–	92,996
Operating Cost $/y	1,988,145	1,242,871
Utility Saving $/y	–	745,272
Capital Cost of add. H.E $/y	–	113,307
Net Saving $/y	–	631,965
Pay back period y	–	1.07

7. Conclusion

Heat Exchangers Networks Synthesis has a great benefit in energy conservation in natural gas processing plants for both cases of grass-root or revamped design of the existing plant. Saving of hot and cold utilities reached to 42% and 21% respectively as compared to actual utility consumption of WDGC. These savings can be realized by revamping of the existing plant by adding only two heat exchangers with a pay back period of ~one year.

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