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Graphical Prediction of Optimum Pinch Point Value with AEA Software Simulation and Validation Applied in Closed Cycle Gas Power Plant

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ABSTRACT

Studying industries energy saving is very important prospect for many researchers in the last four decades. In this respect, better process heat transfer can be achieved to improve process operating and capital cost. Thereafter, obtaining higher amount of heat recovery, which will help to reach system optimum heat exchanger network design. Application of Pinch analysis (PA) in our current study, was found to be as an effective method towards economic solution and assessment for all system thermal processes. Whereby, minimizing energy losses, and thus, prediction of maximum energy saving. In addition, application of "Aspen Energy Analyzer (AEA)" simulation software assist our effort to optimize Heat Exchanger Network design (HEN), with various application scenario towards best design. This study represents a "Case study" as a Brayton closed cycle gas turbine power plant in Al-khairat district, which is one of a number of sites used to generate electricity for Iraq national grid. However, the plant original design is open cycle. This study, represent an attempt to apply (PA) in system closed cycle model with the same working conditions. The results predicted, on the contrary of open cycle, that using closed cycle (PA) with temperature difference ΔTmin can be acceptable with several design propositions. The optimum (ΔTmin = 15°C) were evaluated in the closed cycle system pinch analysis, thereby the maximum Qrec. process that minimize the QHmin & QCmin requirement were identified by the software simulation for the best HEN design. These results were found as Qrec. = 318.330 MW, QHmin = 88.607 MW and QCmin =39.564 MW.

1. INTRODUCTION

PA method is developed in last four decades, is particularly used in thermal process to predict the maximum energy saving and hot & cold utility requirement. Thereby, optimum design for HEN can be obtained [1].

Such that energy saving can minimize the operating cost in the process [2] and optimum retrofit for HEN [3]. Applying PA IN the WTPS Wanakbori Gujarat power plant to reach an optimum plant design. Starting with ΔTmin =25℃, so this leads to enhancing the performance of the plant by 47.19% from the 46.78% and decrease the mass of fluid by 0.19 kg/s, which may lead to enhance the plant performance [4, 5]. Applied PA in naphtha unit to reach to optimum HEN design for the plant with ΔTmin =16℃, there is no improvement in the cost of the process conducted due to decreasing heat and cold loading [6].

Choosing ΔTmin value of 10℃ [7], PA resulted in good savings of energy for heat utility and cold utility requirement. However, the retrofit of HEN design is important to reach to optimum design for maximum heat recovery Qrec., lead to decrease in CO_2 emissions from the plant [8].

The fact that selecting any value of ΔTmin will be subjected to a tradeoff between energy cost and capital cost. Such calculation and with the help of specific chart to arrive at the proper cost-wise results. The composite curve shows graphically the smallest distance between hot composite curve (HCC) and cold composite curve (CCC), where a positive value of ΔTmin must be assigned, i.e. for ΔTmin > 0. Qrec. is connected with the value ΔTmin so heating and cooling utility are also related to the change with ΔTmin [9].

The design of HEN and the retrofit for it to arrive to better solution for the plant is depending on the value for temperature difference between hot and cold utility [10]. Several published work [11-13] have investigated operating and capital cost with respect to specific value of ΔTmin in order to improve heat transfer process and thereby arrive at the best HEN design.

The optimum HEN design is subjected to tradeoff between energy and capital cost and the period of lifetime of HEN [14].

In some designs of HEN is with stream splitting and this method gives a good solution for heat transfer in the process [15]. There are methods to reach to optimum design for HEN with differential evolution to identified the heat loads in the HE [16].

All of the above reviewed research applied PA to improve system performance in terms of operating or capital costs.

However, a selective operating condition was almost a common approach for all researches.

Since (ΔTmin) is a key factor in this respect, then our current work is evaluation attempt for optimum (ΔTmin) graphically to identity maximum Qrec. process that minimize QHmin & QCmin requirement and this we believe is economic achievement.

It is clear from the general theoretical and practical work of the above published studies, PA based on the mathematical and graphical approach is almost always arrive at similar conclusion with respect to energy saving. Therefore, the case study attempt in this paper will be applied to closed power cycle with operating conditions similar to that of Al-khairat gas turbine plant to investigate for possible heat recovery (Qrec.) in all cycle thermal process.

In this respect, the optimum (ΔTmin) should be predicted in order to identify the maximum Qrec. process that minimize the QHmin & QCmin requirement using the software simulation for the best HEN design.

At the end of this Introduction, and in order to achieve the above design objectives, the paper project will be conducted according to the following work program:

- 2. THEORETICAL OBJECTIVES.
- 3. MATHEMATICAL MODELLING.
- 4. ACTUAL GRAPHICAL PREDICTION.
- 5. COMPUTER SOFTWARE APPLICATION FOR CLOSED SYSTEM DESIGN.
- 6. RESULTS AND DISCUSSION.
- 7. CONCLUSIONS AND RECOMMENDATIONS.

2. THEORETICAL OBJECTIVES

2.1 General introduction

PA is developed by linnhoff from Leeds University in his Ph.D study in 1977 for minimizing the energy consumption in a process and reach better heat transfer and heat recovery . He noticed that there is an integration for heat in the process and established the foundation for such analysis, to minimize the total cost of the process connected with the optimum design for heat transfer in the field.

Generally, the PA is based on thermodynamic principles, beginning with the heat and mass balance to identify the hot and cold streams in the process. There by, hot stream need cooling, and the cold stream need heating. Thus integration between them for all the system, is what the PA method is all about [1].

Generally, graphical solution is used in PA problems which comes from two principle diagrams, both of which apply temperature- enthalpy (T-H) relationship. This is symmetrized in Table 1:

Table 1. Compared between CC & GCC

I- Composite Curve (CC)	II-Grand Composite Curve (GCC)
Figure 1 represent an example of hot & cold (CC) with selected ΔTmin value. Whereby, minimum heating & cooling utilities (QHmin, QCmin) as well as (Qrec.) can be derived with respect to the assigned ΔTmin. It should also be noted that at the pinch point, there is no heat flow.	Similarly, Figure 2 represent an example of (GCC) which is plotted from shifted temperature level composite curves. It indicates the difference between the heat available from the process hot streams and the heat required by the process cold streams, relative to the pinch, at a given shifted temperature. Thus, the GCC is a plot of the net heat flow against the shifted (interval)temperature.

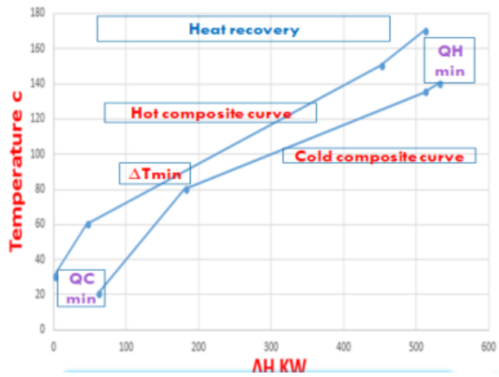


Figure 1. Composite curve

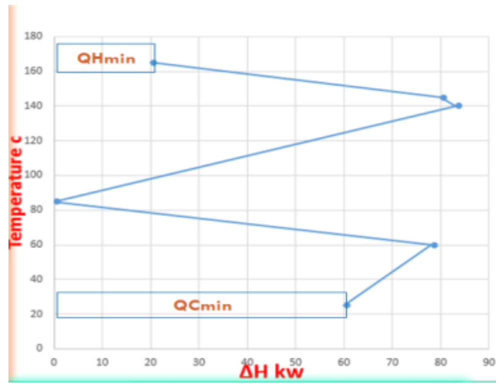


Figure 2. Grand composite curve

2.2 Gas turbine power plant

Gas turbine power plant used to generate electricity for the national grid, constitute three major parts in the open cycle, first the compressor, combustion chamber and finally the turbine, as shown in the illustration of Figure 3 [17].

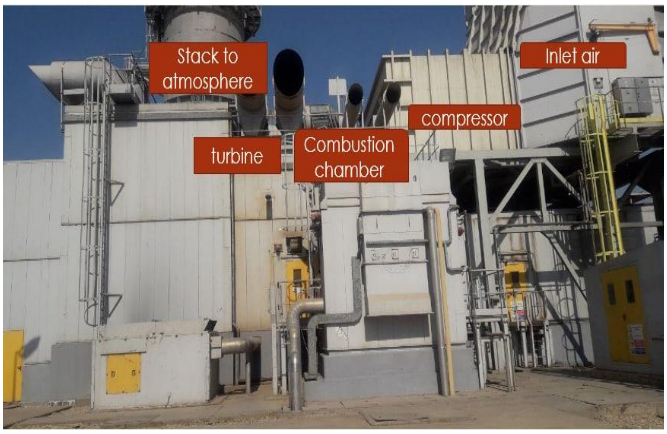


Figure 3. Gas turbine power plant

Gas power plant is represented thermodynamically by Brayton cycle, and consist of four major parts, namely, compressor; combustion chamber; turbine and finally the cooling water, and with air as working fluid.

The same principles are applied whether the cycle is open or closed type. Whereby, an extra process is included in the closed cycle, by which cooling the working fluid before recycling it back to the compressor, as illustrated schematically in Figure 4 and P-V diagram as in Figure 5 [17].

Therefore, closed cycle system study will be selected with the appropriate mathematical modelling.

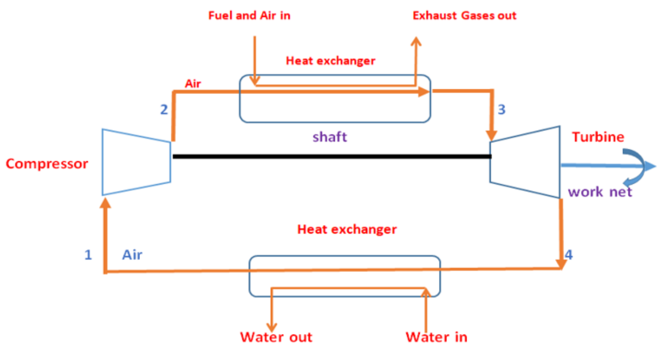


Figure 4. Schematic for Gas turbine power plant (closed cycle)

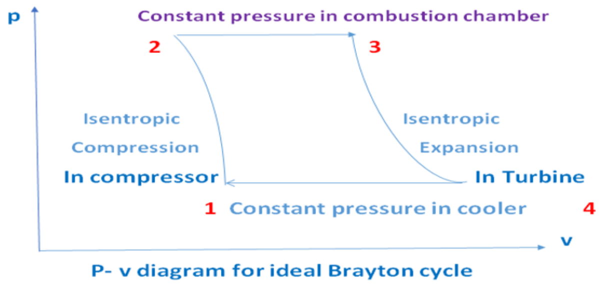


Figure 5. Thermodynamic diagram for Brayton cycle (closed cycle)

2.3 Applied pinch method in the Al-Khairat power plant

Mathematical modelling and PA method were applied to the Al-Khairat closed cycle gas power plant. This site consists of 10 (125MW) electricity generating frame 9Eunits, manufactured by General Electric (GE) industries. As far as this work is concerned, all units were examined, and unit No.3 were chosen for modelling and PA, for its stable working conditions.

The objectives of this study are:

1. calculate Qrec. In the power plant.
2. calculate QHmin in the power plant.
3. calculate QCmin in the power plant.
4. design the HEN for the power plant.

3. MATHEMATICAL MODELLING

3.1 Theoretical model

Several assumptions were made prior to the theoretical analysis steps. These are:

1. Air is the cycle working fluid.
2. Fuel mass flow is neglected compared high air mass flow.
3. The same (pressure & temperature) in all stages in the power plant.

The mathematical modelling used in the analysis is based on the following:

I- heat load in all plant streams, based on the 1th law of thermodynamics is "an expression of the conservation of energy principle" [17]:

$$Q - W = H$$

But W=0 because there is no mechanical work when it calculates heat load, and heat load can be expressed as:

$$Q = \dot{m} \times Cp \times \Delta T \tag{1}$$

II- efficiency calculation for the power plant is:

$$\eta = P \,/\, Qadd \tag{2}$$

where, the efficiency "The fraction of the heat input that is converted to network output is a measure of the performance of a heat engine and is called the thermal efficiency" [17].

III- Temperature outlet from combustion chamber "1-2 Isentropic compression (in a compressor), 3-4 Isentropic expansion (in a turbine) and P2= P3 and P4= P1" [17]:

$$\frac{To.cc}{To.tr} = \left(\frac{Po.cc}{Po.tr}\right)^{\frac{(k-1)}{k}} \text{ where (k=1.4)} \tag{3}$$

IV- shifted temperature for all streams with ΔTmin "to allow for the maximum possible amount of heat exchange within each temperature interval. The only modification needed is to ensure that within any interval, hot streams and cold streams are at least ΔTmin apart. This is done by using shifted temperatures" [1].

$$for\ hot\ stream = Thot - \Delta Tmin/2 \tag{4}$$

$$for\ cold\ stream = Tcold + \Delta Tmin/2 \tag{5}$$

V- equation used to calculate heat load in problem table "each interval will have either a net surplus or net deficit of heat as dictated by enthalpy balance, but never both. Knowing the stream population in each interval" [1]:

$$\Delta H = (Si - Si + 1) \times (\sum CPhot - \sum \text{CPcold}) \tag{6}$$

∑CPhot=summation of specific heat in hot streams(kJ/kg.K).

∑CPcold=summation of specific heat in cold streams(kJ/kg.K).

3.2 Theoretical estimation

Acquisition of thermal data were actually obtained from the plant control facilities and from GE documents illustrated Figure 6:

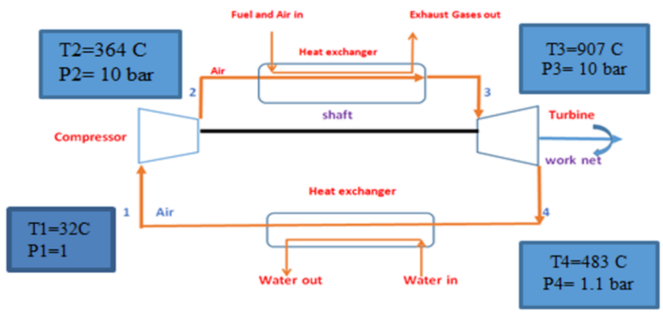


Figure 6. Thermal data for (P and T) in the closed cycle

The specific heat (Cp) is temperature dependent variables, while mass flow rate in all stages is constant (391.2kg/s) for closed cycle. Furthermore, heat load calculation was conducted using Eq. (1). These results are illustrated in the Table 2.

Table 2. Results for heat load in power plant

No	stream	Ts (°C)	Tt (°C)	Cp kJ/kg.K	$\dot{m}$ kg/s	CP kW/K	Δ H MW
1	HOT	907	483	1.0884	391.2	425.78	180.5
2	HOT	483	32	1.0053	391.2	393.27	177.4
3	COLD	364	907	1.267	391.2	495.65	269.2
4	COLD	32	364	1.061	391.2	415.06	137.8

Efficiency evaluation for closed system power plant by the use of Eq. (2),

$\eta = P/Qadd$=90MW/269.2MW(100)=0.3343=33.43%

From the GE documents, the fuel price is (35.85 ID/lit) & its heating value (LHV) is (42447kJ/kg).

Since (η =33.43%), and (LHV=42447kJ/kg), then η=P/Qf=90MW/(42447)× $\dot{m}f \Rightarrow \dot{m}f$=6.348*kg/s*.

But the actual fuel rate from plant data is (6.833*kg/s*), so percent saving of mass of fuel is:

6.833 - 6.348/6.833=0.0709=7.098%

Every unit in the plant is fuel consumption (27.5 m^3/hr) from GE documents.

Cost of fuel per hour=35.85 ID×1000 liter×27.5 m^3/hr=985,875 ID/hr.

Saving cost per hour=985,875×0.0709=69898.53 ID/hr.

Annual cost reduction= $\frac{1}{hr}\cdot\frac{24hr}{day}\cdot\frac{30days}{month}\cdot\frac{12month}{year} = 8640hr/yr$.

Annual cost reduction $\left(\frac{ID}{yr}\right) = 69898.53\left(\frac{8640hr}{yr}\right) = 604(10^6)$.

Drawing the (T-H) after calculating the ΔH in all streams in the power plant, the results is illustrated in the Figure 7.

In this figure is clear there is region between hot and cold CC which represent ΔTmin, and therefore, PA can apply on the power plant. Now applying system PA for a range of (5, 10, 15, 20 and 25) °C as a specific in turn values of ΔTmin, following the same procedure each time to evaluate QHmin, QCmin, and Qrec.

First consideration therefore, is (5°C) ΔTmin, and PA is carried out to draw CC& GCC diagrams according to the following procedure [1]:

I. Apply Eqns. (4 & 5) to evaluate shifted temperature for all streams in the closed cycle with choosing ΔTmin to allow for the maximum possible amount of heat exchange within each temperature interval and this method is help us to know the streams who rejected or received heat by enthalpy balance by using Eq. (6) for each stream as illustrated in Table 3.

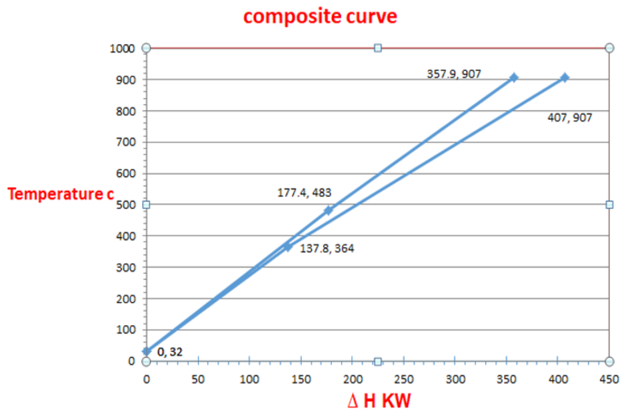


Figure 7. Composite curve for closed cycle

Table 3. Shifted temperature for ΔTmin=5°C

No	stream	Ts (°C)	Tt (°C)	Shifted temp. (°C)	Shifted temp. (°C)
1	HOT	907	483	904.5	480.5
2	HOT	483	32	480.5	29.5
3	COLD	364	907	366.5	909.5
4	COLD	32	364	34.5	366.5

II. Apply problem table (temperature intervals) is showing in Figure 8.

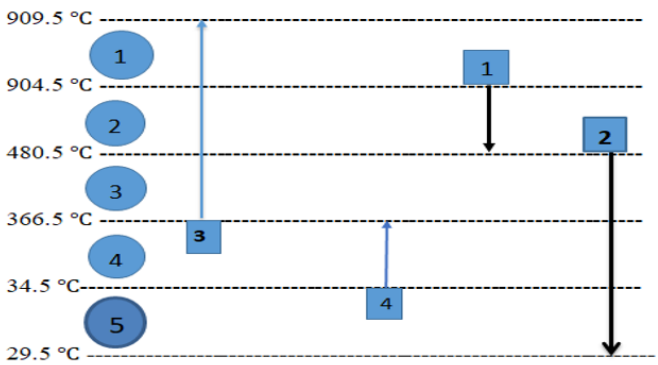


Figure 8. Problem table for closed cycle ΔTmin= 5°C

III. Calculate the ΔH for all streams to specified the surplus and deficit streams in the plant by applying Eq. (6) as illustrated in the Table 4:

Table 4. Surplus and deficit for closed cycle in ΔTmin=5°C

	Interval number	Si- Si+1 (°C)	∑CPhot -∑CPcold (kW/°C)	ΔHi(kW)	Surplus or deficit
S1=909.5°C					
S2=904.5°C	1	5	-495.65	-2478.25	deficit
S3=480.5°C	2	424	- 69.87	-29624.88	deficit
S4=366.5°C	3	114	- 102.38	-11671.32	deficit
S5=34.5°C	4	332	-21.79	-7234.28	deficit
S6= 29.5°C	5	5	+393.27	+1966.35	surplus

IV. Do the infeasible heat cascade step using data from Table 4, as illustrated in the Figure 9:

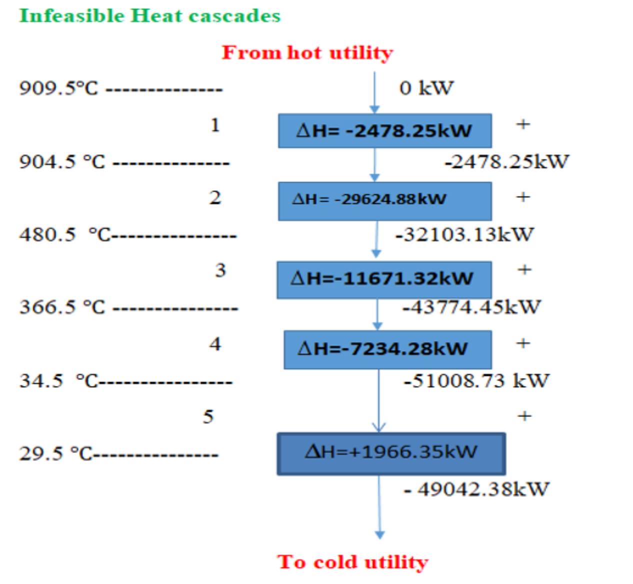


Figure 9. Infeasible heat cascade for ΔTmin=5°C

V. Choosing minimum heat load, in this case is at T=34.5°C with ΔH=-51008.73 kW. Add this heat load to heat cascade again from hot utility [1].

VI. Add the value of minimum heat load and start the feasible heat cascade to arrive to temperature where ΔH equal zero. This temperature represents pinch point, as illustrated in the Figure 10:

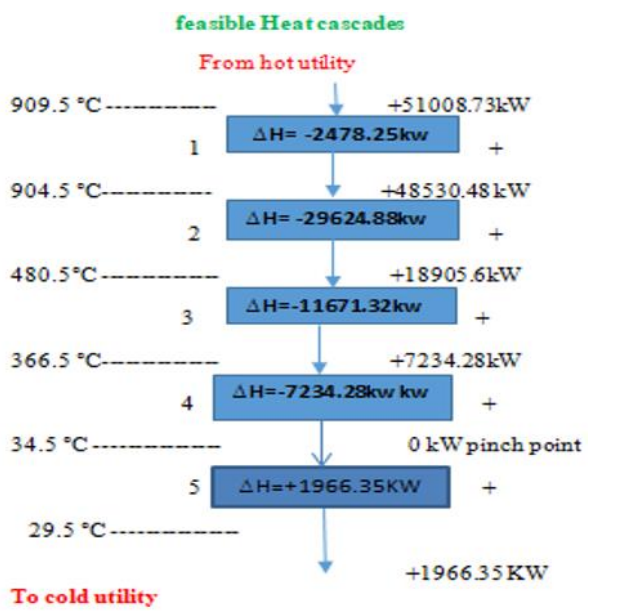


Figure 10. Feasible heat cascade for ΔTmin=5°C

So the results for applying pinch method for ΔTmin=5°C is:

Pinch point (°C)	Pinch hot point (°C)	Pinch cold point (°C)	QHmin MW	QCmin MW	Qrec. MW
34.5	37	32	51.008	1.966	355.929

Now by applying ΔTmin=5°C in the CC and shift the cold CC to reach to region where the ΔTmin between hot and cold CC curve equal to 5°C, at which values of QHmin, QCmin and Qrec. are recorded. As illustrated in the Figure 11:

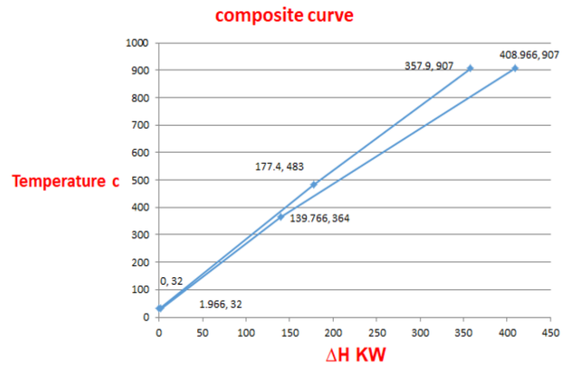


Figure 11. Composite curve for closed system with ΔTmin=5°C

This analysis procedure is repeated for the other specified temperature (10,15,20 and 25) °C, and the results is illustrated below in the Table 5.

Table 5. Value of QHmin, QCmin and Qrec. for different ΔTmin

ΔTmin °C	Qrec. MW	QHmin MW	QCmin MW
5	356.929	51.008	1.966
10	353.963	52.975	3.932
15	351.996	54.941	5.899
20	350.03	56.907	7.865
25	348.064	58.874	9.831

3.3 Computer program

The computer program used in our work is Aspen Energy Analyzer AEA-Version V11-2019, by but the data obtained from the power plant (T, Cp and inlet & outlet mass flow rates) in all streams in the process is used in this program.

4. ACTUAL GRAPHICAL PREDICTION

For all the range of ΔTmin between hot and cold composite curves by applied PA method with theoretical calculations there are Qrec. possible is found and the results for QHmin, QCmin and Qrec. Is shown in Table 6.

Table 6. Value for QHmin, QCmin and Qrec. For different ΔTmin

ΔTmin °C	Qrec. MW	QHmin MW	QCmin MW
5	356.929	51.008	1.966
10	353.963	52.975	3.932
15	351.996	54.941	5.899
20	350.03	56.907	7.865
25	348.064	58.874	9.831

By calculating the percent value for each item in the Table 6 the results is:

For ΔTmin=5°C

Qrec.= 356.929 – 348.064/ 356.929=2.48%

QHmin= 58.874 – 51.008/58.874=13.36%

QCmin=9.831–1.966 /9.831=80%

So the results for all value showing in the Table 7 below:

Table 7. Percent value for Qrec., QHmin and QCmin

ΔTmin °C	Qrec. MW %	QHmin MW%	QCmin MW %
5	0	0	0
10	0.83	3.34	20
15	1.38	6.68	40
20	1.93	10.02	60
25	2.48	13.36	80

The results for Qrec. & QCmin with ΔTmin are presented in Figure 12.

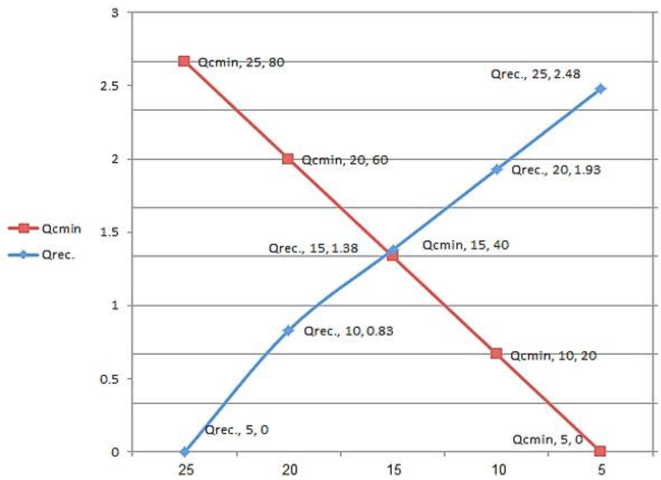


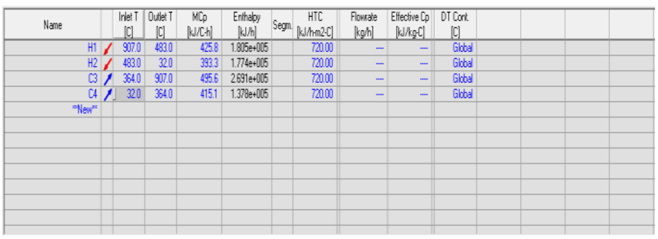
Figure 12. Qrec. And QCmin with ΔTmin

From Figure 12 it's clear that there is cross over between (Qrec. & QCmin) lines at (ΔTmin=15°C), which represent the prediction of the optimum pinch point, and the value of (Qrec.) at this temperature is (351.996 MW).

5. COMPUTER SOFTWARE APPLICATION FOR CLOSED SYSTEM DESIGN

AEA simulation software is applied to the closed cycle system for a range of ΔTmin (5, 10, 15, 20 and 25) Because the PA method depends to ΔTmin between hot and cold utility and by this ΔTmin reach to optimum design for HEN for the process and this ΔTmin is different and there is no constant value for it, so by choosing different ΔTmin and make comparison between them to arrive to better ΔTmin for the process [1].

The results are shown in the (CC) in Figures 13 and 14.



Name		Inlet T [C]	Outlet T [C]	MCp [kJ/C-h]	Enthalpy [kJ/h]	Segm.	HTC [kJ/h-m2-C]	Flowrate [kg/h]	Effective Cp [kJ/kg-C]	DT Cont. [C]
H1		907.0	483.0	425.8	1.805e+005		720.00	---	---	Global
H2		483.0	32.0	393.3	1.774e+005		720.00	---	---	Global
C3		364.0	907.0	495.6	2.691e+005		720.00	---	---	Global
C4		32.0	364.0	415.1	1.378e+005		720.00	---	---	Global
New										

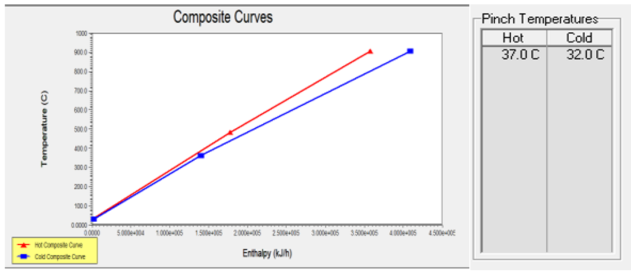
Figure 13. Thermal data for closed system

The results for AEA simulation software for the range of ΔTmin between (5, 10, 15, 20 and 25) °C is illustrated in the Table 8.

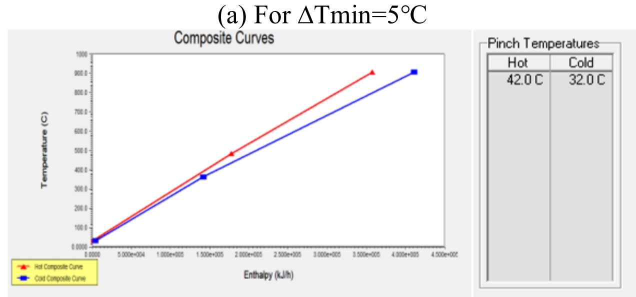
The results for AEA simulation software is showing that there is decrease in Qrec. and increase in QHmin and QCmin with increase ΔTmin.

Table 8. Qrec., QHmin and QCmin for AEA simulation

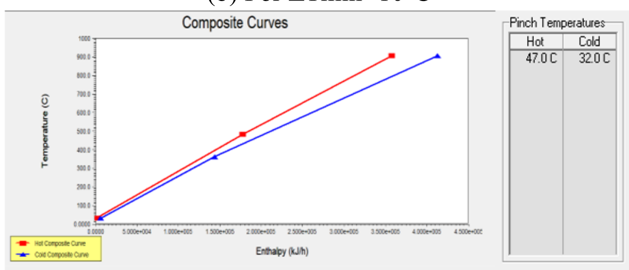
ΔTmin °C	Qrec. MW	QHmin MW	QCmin MW
5	356.929	51.010	1.966
10	353.963	52.980	3.933
15	351.996	54.940	5.899
20	350.03	56.910	7.865
25	348.064	58.870	9.832



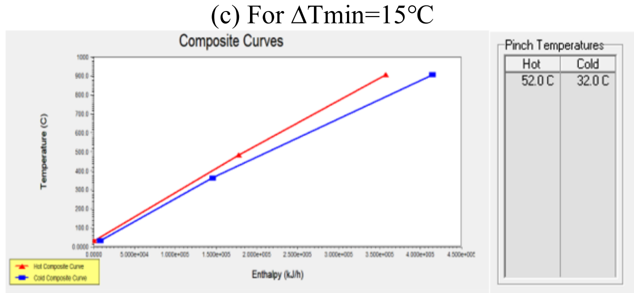
(a) For ΔTmin=5°C



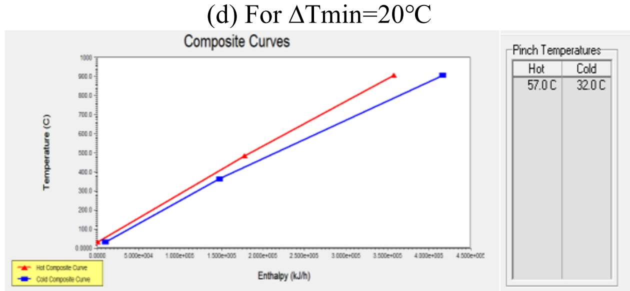
(b) For ΔTmin=10°C



(c) For ΔTmin=15°C



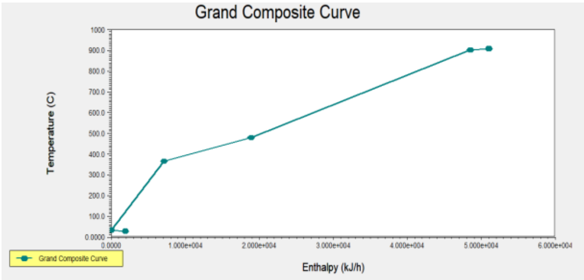
(d) For ΔTmin=20°C



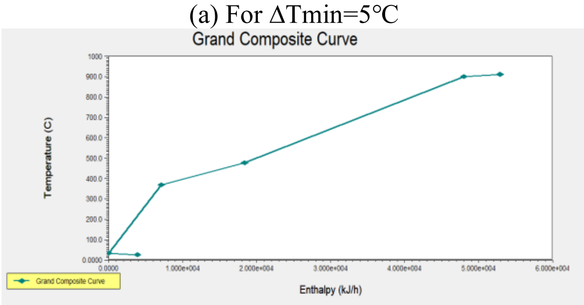
(e) For ΔTmin=25°C

Figure 14. CC for closed cycle for (a) ΔTmin=5°C, (b) ΔTmin=10°C, (c) ΔTmin=15°C, (d) ΔTmin=20°C, (e) ΔTmin=25°C

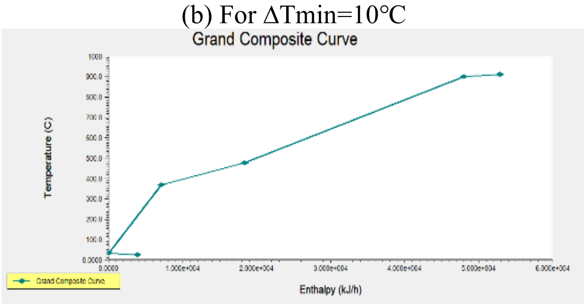
Thereafter, system GCC are applied for the same temperature range (5, 10, 15, 20 and 25), and the results are shown in the Figure 15.



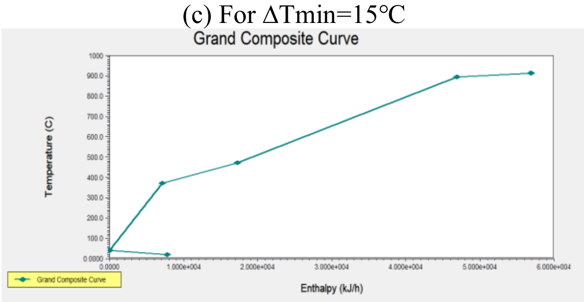
(a) For ΔTmin=5°C



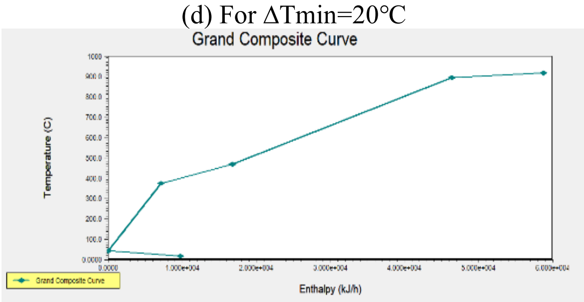
(b) For ΔTmin=10°C



(c) For ΔTmin=15°C



(d) For ΔTmin=20°C



(e) For ΔTmin=25°C

Figure 15. GCC for closed system for (a) ΔTmin=5°C, (b) ΔTmin=10°C, (c) ΔTmin=15°C, (d) ΔTmin=20°C, (e) ΔTmin=25°C

6. RESULTS AND DISCUSSION

The theoretical calculations for closed cycle is illustrated in the Table 9.

The CCs for the system ΔH are presented in Figure 16.

Table 9. Heat loads for power plant

No	stream	Ts (°C)	Tt (°C)	Cp kJ/kg.K	ṁ kg/s	CP kW/K	Δ H MW
1	HOT	907	483	1.0884	391.2	425.78	180.5
2	HOT	483	32	1.0053	391.2	393.27	177.4
3	COLD	364	907	1.267	391.2	495.65	269.2
4	COLD	32	364	1.061	391.2	415.06	137.8

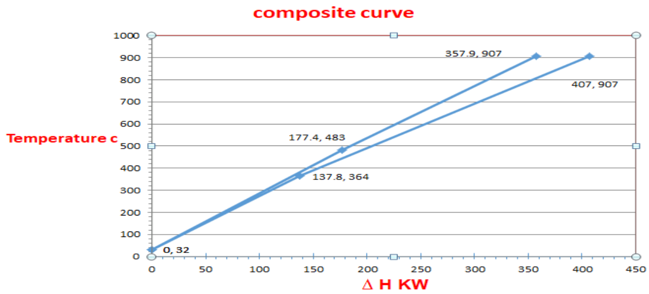


Figure 16. CC for closed cycle

So it's clear from the CC that there is a region where PA could be applied at which possible heat transferred between the hot and cold composite curves. Applied the values of heat loads in the AEA simulation program and the results is illustrated in Figure 17.

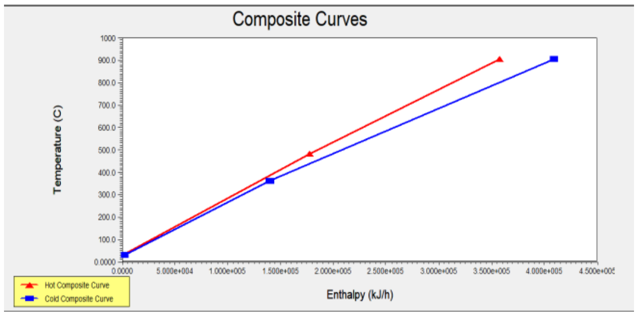
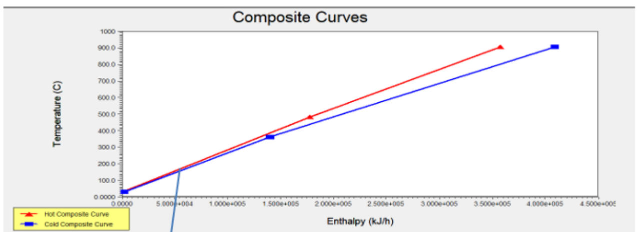


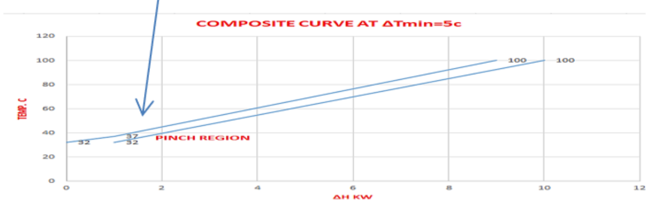
Figure 17. Composite curve for closed cycle by AEA program

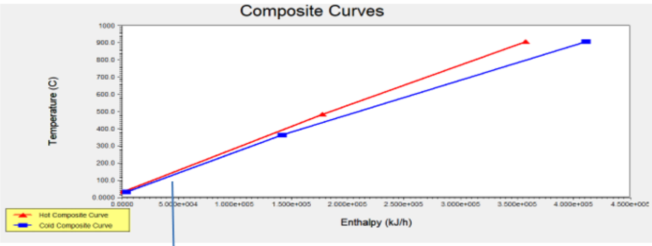
Now applied PA in closed cycle for range of ΔTmin between (5, 10, 15, 20 and 25) by AEA simulation software and the results is shown in the Figure 18 below.



(a) For ΔTmin = 5°C

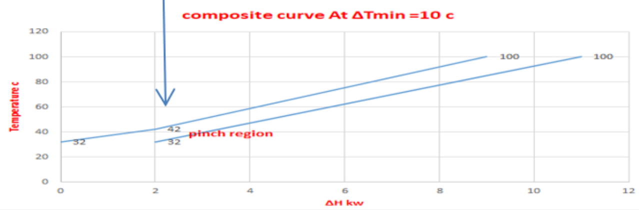
Zoom for pinch region

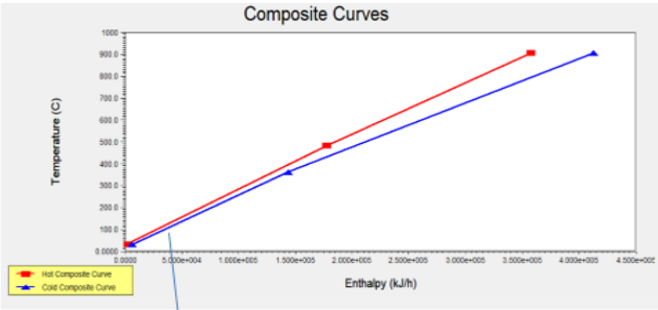




(b) For ΔTmin = 10°C

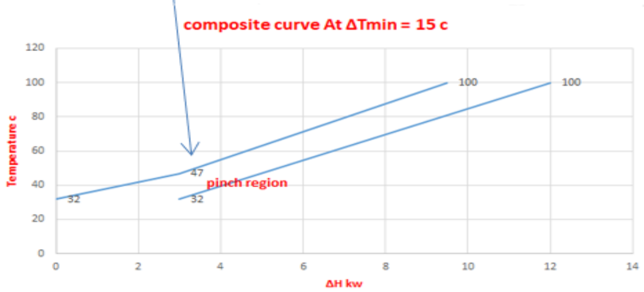
Zoom for pinch region

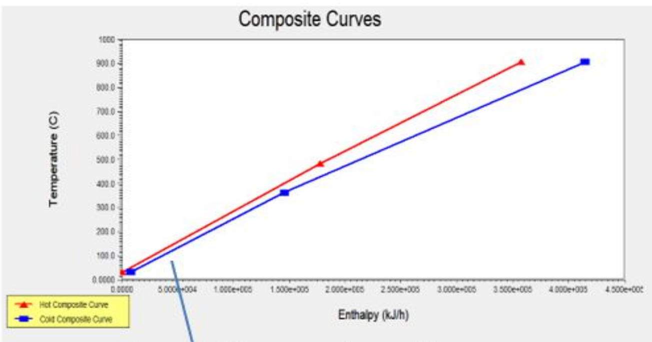




(c) For ΔTmin = 15°C

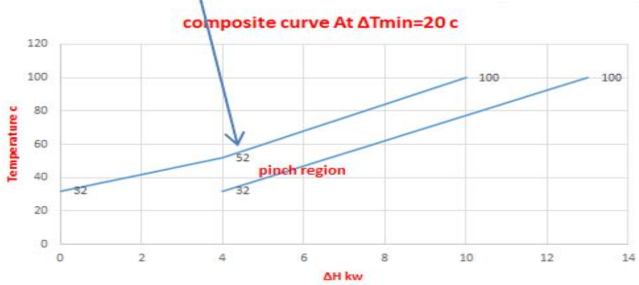
Zoom for pinch region

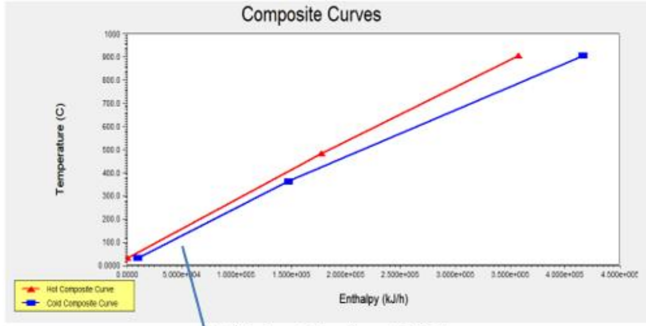




(d)For ΔTmin = 20°C

Zoom for pinch region





(e) For ΔTmin = 25°C

Zoom for pinch region

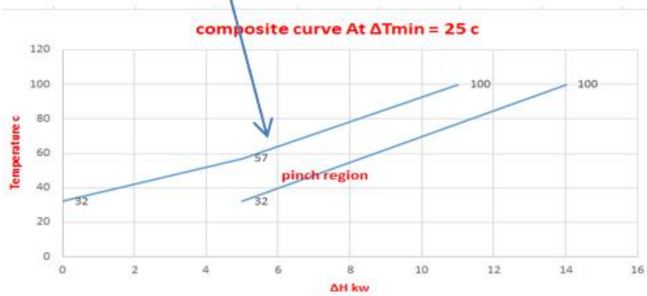


Figure 18. CC for closed system for (a) ΔTmin=5°C, (b) ΔTmin=10°C, (c)ΔTmin=15°C, (d) ΔTmin=20°C, (e) ΔTmin=25°C

Theoretical (PA) application and drawing hot and cold CCs for the specified range of ΔTmin, Qrec. Appeared to be possible. Whereby, the results for Qrec., QHmin and QCmin is shown in Table 10.

Table 10. Qrec., QHmin and QCmin for closed cycle

ΔTmin °C	Qrec. MW	QHmin MW	QCmin MW
5	356.929	51.008	1.966
10	353.963	52.975	3.932
15	351.996	54.941	5.899
20	350.03	56.907	7.865
25	348.064	58.874	9.831

Validation of the simulation software prediction with theoretical calculations is very important to ensure that such software is reliable, and could be used for different operating conditions, or even for different systems. Both results are presented in Table 11, clearly demonstrate acceptable similarity.

Table 11. Validation for simulation software

ΔTmin °C	Qrec. MW	QHmin MW	QHmin MW from program	QCmin MW	QCmin MW from program
5	356.929	51.008	51.010	1.966	1.966
10	353.963	52.975	52.980	3.932	3.933
15	351.996	54.941	54.940	5.899	5.899
20	350.03	56.907	56.910	7.865	7.865
25	348.064	58.874	58.870	9.831	9.832

For all the specified range of ΔTmin, there are different Qrec. values. Therefore, the correct process Qrec. and the optimal ΔTmin must be evaluated.

For the optimum ΔTmin (15°C), it's important to know if the mass of fuel has change or not. Therefore, theoretical calculations will be repeated accordingly to evaluate the mass of fuel.

PA is applied for the calculation of:

- In Hot CC

Qrec.=Qtr+Q c.w – QCmin -------1

351.996=180.5+ 177.4 – 5.899

- In Cold CC

Qrec.=Qf+Q comp. – QHmin ---------2

351.996=269.2+137.8 - 54.941

For a comparison purposes, calculate Qf in ΔTmin=5°C & 15°C

I . with the optimum ΔTmin=15°C

Qrec.=351.996 MW

Qcomp.=137.8 MW

QHmin=54.941 MW

Qrec.=Qf+Q comp. – QHmin

351.996=Qf+137.8 – 54.941

- So (Qf) at ΔTmin=15°C is (269.2MW)
- And (η) at ΔTmin=15°C=$\frac{power}{Qf} = \frac{90}{269.2} = 0.3343$
- it's the same efficiency, and so, fuel cost almost unchanged.
- From equation 1 and 2 Qrec. is the same from both equations.

II. calculate Qf in ΔTmin=5°C & 15°C

✓ for ΔTmin= 5°C

Qtr+Q c.w – QCmin=Qf+Q comp. – QHmin

180.5+177.4 – 1.966=Qf+137.8 – 51.008

So Q f=269.142 MW

Qf= $\dot{mf} \times$ C.V

269.142= $\dot{mf} \times 42447$

So $\dot{mf}$ =6.34066 kg/s

✓ for ΔTmin=15°C

Qtr+Q c.w – QCmin=Qf+Q comp. – QHmin

180.5+177.4 – 5.899=Qf+137.8 – 54.941

So Qf=269.142 MW

Qf= $\dot{mf} \times$ C.V

269.142= $\dot{mf} \times 42447$

So $\dot{mf}$ =6.34066 kg/s

From the above results, it can be concluded that:

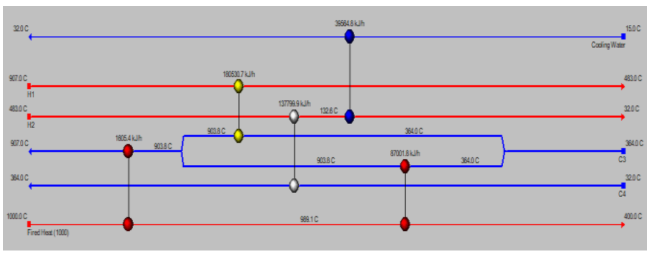
1- The mass flow rate consumption in the different ΔTmin=5°C and 15°C is the same.

2- Design cost decreased due to decrease in Heat Exchanger surface area.

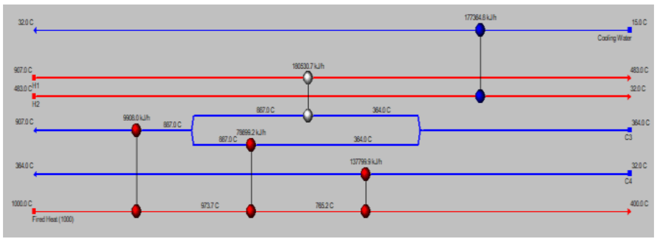
3- Most reference for pinch analysis assume the optimum ΔTmin between=5 to 25°C.

For optimum temperature difference between hot and cold CC ΔTmin=15°C must drawing the HEN design for closed cycle by AEA simulation software and the results is shown below in Figure 19.

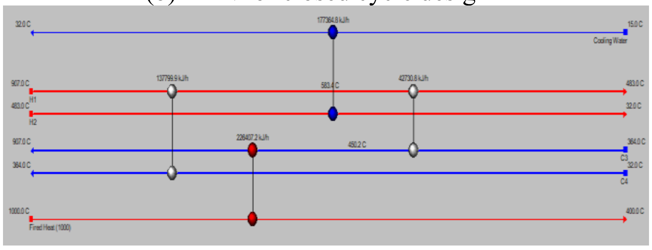
The results for Qrec., QHmin and QCmin for all the designs for optimum temperature difference is illustrated in the Tables 12 and 13.



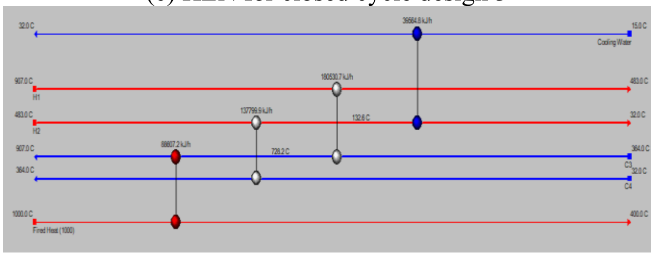
(a) HEN for closed cycle design 1



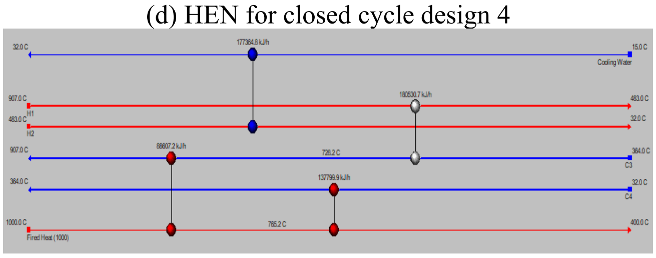
(b) HEN for closed cycle design 2



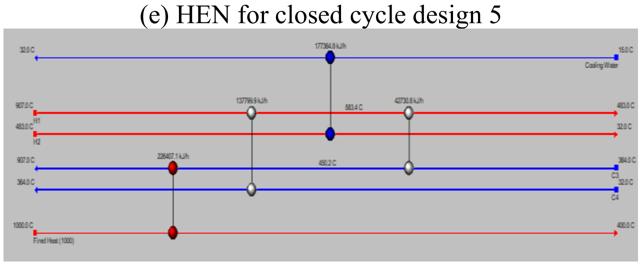
(c) HEN for closed cycle design 3



(d) HEN for closed cycle design 4



(e) HEN for closed cycle design 5



(f) HEN for closed cycle design 6

Figure 19. HEN for ΔTmin=15°C (a) design1, (b) design 2, (c) design 3, (d) design 4, (e) design 5, (f) design 6

Table 12. Qrec., QHmin and QCmin for six design for HEN

ΔTmin °C	Design No.	Qrec. MW	QHmin MW	QCmin MW
15	1	318.330	88.607	39.564
	2	180.530	226.407	177.648
	3	180.530	226.407	177.648
	4	318.530	88.607	39.564
	5	180.530	226.407	177.648
	6	180.530	226.407	177.648

For closed cycle system analysis at optimum temperature difference ΔTmin= 15°C, there are six HEN design predicted by the software simulation, and from these outcomes, we must identify the better design depending on the values of (Qrec., QHmin and QCmin), and the number HE requirement.

From the Table 12 the (Qrec., QHmin and QCmin) values for each design, and through pinch method philosophy [1], aiming to identify the maximum Qrec. process that minimize the QHmin & QCmin requirement. Design (1 and 4) produced the most attractive results.

From Table 13 the results are presented as number of heat exchanger in each design and is it with or without stream splitting, from which it was concluded that two designs (1 & 4) are the better design. In addition, and with respect to Table 13:

Table 13. Number of HE for each design

ΔTmin °C	Design No.	With stream splitting	Number of HE for Qrec.	Number of HE for QHmin	Number of HE for QCmin
15	1	Yes	2	2	1
	2	Yes	1	3	1
	3	No	2	1	1
	4	No	2	1	1
	5	No	1	2	1
	6	No	2	1	1

Table 14. Characteristics of the selected designs (1) and (4)

Design (1)	Design (4)
With stream splitting	Without stream splitting
Higher cost of stream splitting design	Lower cost of none stream splitting design
2 HE in hot utility	1 HE in hot utility

Finally, from Table 14 the preferred closed cycle design at ΔTmin =15°C is (Design 4) where:
for Qrec.=318.330 MW, QHmin=88.607 MW and QCmin =39.564 MW.

7. CONCLUSIONS AND RECOMMENDATIONS

In this study, the investigation for energy saving in the Al-khairat gas turbine power plant is presented to make assessment for the thermal process in the plant to specified the maximum Qrec. and QHmin & QCmin by applied PA method with closed Brayton cycle with the same operating condition in Al-khairat power plant by applied theoretical calculations and with AEA simulation software.

7.1 Conclusions

By calculating ΔH in all the streams in power plant and applied it firstly in the (T-H) diagram and drawing CC to obtained hot and cold composite curve and finally in the AEA simulation software,

1. Can applied PA method in closed cycle because there is heat transfer area between hot and cold CC.
2. Applied range of ΔTmin between hot and cold composite curve (5, 10, 15, 20 and 25°C).
3. There are Qrec., QHmin and QCmin for each ΔTmin in the range.
4. There are more than one design for HEN for each ΔTmin.
5. Choosing the optimum ΔTmin for closed cycle by predicted it by drawing the values for Qrec. And QCmin and the optimum ΔTmin is in the 15°C.
6. The values for Qrec., QHmin and QCmin for design four is respectively for Qrec.=318.330 MW , QHmin=88.607 MW and QCmin =39.564 MW.
7. The data for the power plant is obtained by actual site-visit and recorded from the control room facilities. Monitoring such values until it reaches steady level to be considered and recorded for paper analysis. In addition, the methodology depends on step by step PA procedure to reach a specific result which predict the chance to apply PA. Otherwise, choosing another temperature difference between hot and cold composite curves. This is time consuming effort, adding to that careful acquisition of data makes considerable limitation to conduct the test program.

7.2 Recommendations

1. In Iraq the gas turbine power plant used is open Brayton cycle, so the recommendation to used closed Brayton cycle for reasons mentioned in this study.
2. For open cycle to benefit from the exhaust gases from turbine by installed heat recovery steam generation.
3. Future research can involve wide range of temperature difference ΔTmin up to maybe 50 ℃. Comparison between such results will obviously allow high accuracy for the specified ΔTmin processes.

Calculation of process operating and capital cost for process and thus comparison between them with temperature difference ΔTmin will present better opportunity for optimum heat exchanger network design.

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NOMENCLATURE

CP	heat capacity, kW.K^{-1}
Cp	specific heat, kJ. kg^{-1}. K^{-1}
Q,ΔH	heat load, kW
P	power, kW, pressure, bar
T	temperature, K
ṁ	mass flow rate, kg. s^{-1}
Si,Si+1	temperature interval, K
C.V	lower heating value, kJ. kg^{-1}
K	air constant, --

Greek symbols

Δ	difference, --
η	efficiency, --
∑	summation, --

Abbreviations

HE, HEN	Heat exchanger, HE Network
QC, QH	Cold utility, Hot utility
M Wt	Molecular Weight
PA	Pinch Analysis
CC	Composite Curve
GCC	Grand Composite Curve
NG	Natural Gas
LDO	Distillate Gas Oil
HFO	Heavy Fuel Oil
GE	General Electric
AEA	Aspen Energy Analyzer

Subscripts

s	supply
t	target
1,2,3,4	state points
e, o	exit, out
i	inlet
cc	combustion chamber
tr	turbine
rec.	recovery
f	fuel
min	minimum
comp.	compressor
c.w	cooling water