A HEAT INTEGRATION STUDY CONSIDERING VARIABLE PHYSICAL PROPERTIES

A DISSERTATION

Submitted in the partial fulfilment of the

requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

CHEMICAL ENGINEERING

(With specialization in Industrial Pollution Abatement)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work being presented as the Dissertation report entitled "**A HEAT INTEGRATION STUDY CONSIDERING VARIABLE PHYSICAL PROPERTIES**" in partial fulfilment of the requirements for the award of the degree of M.Tech. (With Specialization in Industrial Pollution Abatement) and submitted in the department of Chemical Engineering of the Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from June 2013 to June 2014 under the esteem supervision of **Dr. Shabina Khanam** Department of Chemical Engineering, Indian Institute of Technology Roorkee, Roorkee, India. The matter presented in this report has not been submitted by me for the award of any other degree of this or any other institute.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

The technology of energy integration is an outstanding approach for reducing the consumption of energy and increases the profit throughout the process. Due to continuous increase in the cost of energy and depletion of conventional resources of energy also day by day growing environmental problem there are strict need of to reduce the energy consumption by improving the existing process. In refineries except the cost of crude, energy took huge sum of money which can be modified if a better design being presented and has therefore become our focus.

Lots of technique has been presented for the study of heat exchanger network problems like tree searching, mixed integer non linear programming, genetic algorithm, graphical method. Pinch technology also called graphical method. In all these method this work is limited to pinch technology because it is the most notable method in all method due its easy technique and robustness.

In pinch technology the physical properties are taken as constant but in reality physical property especially heat capacity is a function of temperature which has significant effect on the design of heat exchanger network. So to show the temperature dependency of streams three problems have been taken and pinch technology has been applied. First two problems are formulated problem and the third one is industrial problem of sponge iron industry. First two problems have two hot and two cold streams while the problem 3 has four cold and four hot streams. Energy, area, no. of unit, cost and super targeting have been performed first by taking constant heat capacity and then by variation in heat capacity for all the three problems. It has been seen that for the problem 1 when consider variation in physical property both utility increases but area decreases, overall total annual cost increases. The same trend are observe in problem 2 and problem 3, which shows that by considering the variation in CP increases utility so it should be kept in mind while designing the heat exchanger network. Also the final design of HEN is presented for all the three problems taken so for.

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NOMENCLATURE

A	Area m2
CP	Product of steam flow rate and specific heat MW/K
ΔT_{min}	Minimum temperature driving force K
h	Heat transfer coefficient MJ/m^2 K
U	Overall Heat transfer coefficient MJ/m^2 K
u_{min}	minimum no. of units including heater and cooler
Q_h	heating duty MW
Q_c	cooling duty MW
C_h	Cost of heating duty $ MW/yr
C_c	Cost of cooling duty $ MW/yr
CC	Capital cost $
AOC	annual operating cost $
TAC	Total annual cost $
MCP	CP MW/K
HEN	heat exchanger network

Subscript

c	cold
h	hot
i	temperature interval number
min	minimum
opt	optimum
out	outlet
s	source
t	target

CHAPTER 1

INTRODUCTION

Energy integration technology is widely used technique for the reduction of energy consumption throughout the plants. Fuel price are increasing day by day and due to this cost of energy also increases so there is a need to reduce the energy consumption for the process. Different methods such as genetic algorithm [4,5], mixed integer nonlinear programming (MINLP) [23], tree searching algorithm method [24] and pinch technology[18] have been developed for this purpose. Amongst these methods, the present work considers pinch technology. Generally pinch technology uses constant physical properties. However, in real scenario heat capacity is always a function of temperature, which has significant effect in the design of heat exchanger network. This work shows the effect of variation of physical properties on targeting and designing of heat exchanger network (HEN).

The effectiveness of pinch analysis by considering variation in physical properties has been shown by taking three problems. In these problems first two has two hot and two cold streams. Third problem is an industrial problem, which is for the production of sponge iron. It has four hot and four cold streams. For these problems energy target, area target, cost target and supertargeting has been done and design of HEN is also performed.

Nejad et al. [1] applied pinch technology over ammonia plant. They performed energy as well as area target by considering constant and variation in physical properties. They applied pinch technology to show the temperature dependency of streams. Jezowski et al. [11] proposes a method of MINLP for minimum utility heat exchanger when heat capacity are allowed to change within a limit. Due to this pinch location changes which is solved as MILP optimization problem by taking sufficient no. of binary variables.

Very less work has been done considering variable physical properties for the design of HEN. A lot of work has done by genetic algorithm method, pressure optimization, MILP optimization and NLP optimization methods. These are quite tedious method so pinch technology is taken account for variable physical property to show the temperature dependency of streams on energy, area target, etc.

1.1 OBJECTIVES OF PRESENT STUDY

1. To collect the physical properties of streams of HEN based on temperature.
2. To draw the composite curve, grand composite curve & balance composite curve considering constant and variable physical properties and to perform energy targeting, area targeting, no. of unit targeting, cost targeting and supertargeting.
3. To design the HEN and optimize it for targeted values.
4. To compare the network designed for constant and variation in physical properties.

CHAPTER 2

LITERATURE REVIEW

2.1 PINCH ANALYSIS

Linnhoff and Veredevel coined the term “Pinch Technology”. Pinch technology is basically based on the laws of thermodynamics that provide us the minimum energy level for the design of heat exchanger network. Over the last three decades lot of work has been carried out by using this method to save energy across the plants. It provide nearly optimal heat exchanger network to the design engineer. It relies on some heuristic rules. Linhoff B. and Hindmarsh E. [22] first times in 1983 uses this method to design heat exchanger network to achieve maximum energy recovery. Nowadays this technology has been extended to onsite analysis of boiler, heat pumps, refrigeration and turbines.

2.1.1 BACKGROUND

Pinch technology was developed as a heat integration tool by Bodo Linnhoff [16] during his PhD course under the esteemed supervision of John Flower in late 1970s due to increase in the cost of fuel prices day by day. With the help of this technology heating and cooling loads could be reduced upto 30% which contribute huge money in the process. It provides a simple method to systematically analyze the process and utilities around this by the help of laws of thermodynamics. First law provide the energy equation by which get the enthalpy change of the process streams of heat exchanger networks. Second law tells the direction of heat flow ie. Heat flow from hot to cold which prohibit the “temperature crossovers”of hot and cold process streams within the heat exchanger network. Hot streams can only be cooled to a temperature which is defined as ‘temperature approach’. This temperature approach is the minimum allowable temperature difference (ΔT_{min}) of heat exchanger network. The temperature at which this ΔT_{min} is observed is called “Pinch Point”. This pinch provides us the minimum driving force available in the heat exchanger network.

2.1.2 OBJECTIVES OF PINCH ANALYSIS

When a Heat exchanger network has single hot and cold stream then it is easy to get optimum heat exchanger network by heuristic rules, but when if the process streams are more in number then these traditional method become tedious and does not guarantee a better heat exchanger network. As Pinch technology came into existence it not only provide a optimal network but also improved the process. With the energy crisis all over the world all industrialist want to maximize the process to process heat recovery and to reduce the energy utilization by the process as load. To achieve this goal a there is a need of optimal heat exchanger network. With the advent of this technique this problem have been overcome upto some extent.

Pinch analysis is used to calculate the cost of energy needed, pinch temperature and capital cost of heat exchanger networks. Thus the procedure starts ahead of design to calculate minimum external hot and cold utility, network area, no. of units and cost of heat exchanger networks for the given process. Main objective of pinch analysis is that the process should be economically viable which could be achieved by better process heat integration i.e. maximizing process to process heat recovery and by reducing external hot and cooling utility.

2.1.3 STEPS OF PINCH TECHNIQUE

In any pinch analysis problem a well said stepwise procedure is followed either it is a new project or a retrofit situation of heat exchanger network. These steps are as follows: [19]

1. Streams identification
2. Data extraction for process and utility streams
3. Selection of initial Minimum temperature driving force (ΔT_{min}).
4. Construction of Composite curve (CC), Grand composite curve (GCC) and balance composite curve (BCC):
5. Estimation of minimum energy cost target
6. Estimation of HEN capital cost targets
7. Supertargeting
8. Design of heat exchanger network

2.1.3.1 STREAMS IDENTIFICATION

- Hot streams are product streams which will be cooled to a required temperature.
- Cold streams are feed streams which will be heated to a desired temperature.
- Utility streams are those streams which are used to heat or cool the process streams when heat exchange is not practical or economic between process streams.

2.1.3.2 DATA EXTRACTION FOR PROCESS AND UTILITY STREAMS:

For all given hot and cold process streams and utility streams these following thermal data are extracted from the process material and energy balance flowsheets [22]

- Supply temperature (T_s , K)
- Target temperature (T_t , K)
- Heat capacity flow rate (CP, kW/K), which is the product of flow rate and specific heat
- Enthalpy change (ΔH, MW) is associated with the steam passing through the heat exchanger is given by 'First law of thermodynamics'.

$$\Delta H = CP \times (T_t - T_s)$$

2.1.3.3 SELECTION OF INITIAL MINIMUM TEMPERATURE DRIVING FORCE:

Heat exchanger design always adhere with the second law of thermodynamics which forbid the any temperature crossover between hot and cold process streams this is called minimum temperature driving force ΔT_{min} which must be present for a feasible heat exchanger design. This ΔT_{min} represent the bottleneck in the heat recovery of the process. The value of ΔT_{min} is determined by the geometry of heat exchanger and overall heat transfer coefficient.

For a given heat load Q if ΔT_{min} chosen is small then area requirement of HEN increases which in turn increases the capital cost. If ΔT_{min} selected are large then area of HEN decreases and heat recovery also decreases which in turn increases the external hot and cold utility. Higher value of ΔT_{min} results in higher operating and low capital cost. So there is a need to select an optimal ΔT_{min} to start the energy integration of the process. For this purpose Linnhoff March [18] application experience presented ΔT_{min} value for shell and tube heat exchanger.

Oil Refinery industries: 15 - 30 ^{0}C

Petrochemical industries: 10 - 20 ^{0}C

Chemical industries: 10 - 20 ^{0}C

Low temperature process: 3 - 5 ^{0}C

2.1.3.4 CONSTRUCTION OF COMPOSITE CURVE (CC), GRAND COMPOSITE CURVE (GCC) AND BALANCE COMPOSITE CURVE (BCC):

- Composite Curve

  The enthalpy vs. temperature data for all hot streams is combined to give hot composite curve. This represents the heat availability in the "combined hot stream" as a function of temperature. In similar way thermal data of all cold streams is combined to give the cold composite curve. The cold composite curve is shifted towards right in such a way that minimum temperature difference between hot and cold process streams should be equal to ΔT_{min} .Basic reason behind to shift cold composite curve is that heat flows from hot temperature to cold temperature. Therefore hot composite curve always lies above cold composite curve. The temperature at which hot and cold composite curve comes close to each other are called pinch point. The section of hot composite curve below which cold composite curve are not present are cooled by external cooling utility, similarly the section of cold composite curve above which no hot composite are present are heated by external heating utility. The remaining parts of hot and cold composite curve where both hot and cold composite curve are present provide the total heat exchange in the given process streams.

- Grand composite curve

  The energy needed in the process is provided by several utility levels e.g. steam level, hot oil circuit, furnace flue gas and refrigeration level. It is recommended that use low pressure steams instead of high pressure and cooling water instead of refrigeration. Thus composite curve provide the overall energy target but does not provide detail about how much energy needed at different utility level. It is basically a tool in pinch technology used for the selection of appropriate utility levels and for targeting of a given set of multiple utility levels.

2.1.3.5 ESTIMATION OF MINIMUM ENERGY COST TARGET

When ΔT_{min} is chosen minimum hot and cold utility is evaluated from composite curve. GCC provides the utility levels selected to meet the utility requirements. If the unit cost of each hot and cold utility is known to us then cost of energy could be evaluated by following equation.

Total cost of energy = $Q_h x C_h + Q_c x C_c$

Where Q_h = heating duty MW

Q_c = cooling duty MW

C_h = unit cost of hot utility $/MW

C_c = unit cost of cold utility $/MW

2.1.3.6 ESTIMATION OF HEN CAPITAL COST TARGETS:

Heat exchanger network capital cost depends mainly on three factors:

1. The overall area of the network
2. The number of heat exchanger
3. Distribution of area between the heat exchanger network

Pinch technology determine the target for the overall heat transfer area and minimum number of units required in the process prior to detail design of heat exchanger network. It is assumed that the area is evenly distributed across the units. The distribution of area could not be predicted ahead of design.

2.1.3.6.1 AREA TARGET:

To calculate area for a single counter-current heat exchanger it is mandatory to have the knowledge of inlet and outlet temperature of hot and cold streams to calculate log mean temperature difference (LMTD), overall heat transfer coefficient and total heat. The area could be calculated by the following formula[]

$$\text{Area} = Q / (U \times LMTD)$$

The composite are divided into a set of different enthalpy interval in such a way that in each interval the slope of hot and cold composite remains constant. Heat transfer in each interval is assumed vertical pure counter-current. The hot streams in any enthalpy interval at any point exchange heat with the cold streams vertically below it. The total area of heat exchanger network is given by the following formula

$$\text{HEN minimum area} = \sum_i \left[\left(\frac{1}{LMTD} \right) \times \sum_j q_j / h_j \right]$$

Where i = i^{th} enthalpy

J = j^{th} stream

2.1.3.6.2 NUMBER OF UNITS TARGET:

In the designing of minimum energy requirement, no heat transfer across the pinch point because it create dual penalty over HEN so a realistic target for to get minimum number of units is the sum of the target evaluated both above and below the pinch separately.[19]

Minimum number of heat exchanger required in the MER design

$$N_{min} = [N_h+N_c+N_u-1]_{\text{above pinch}} + [N_h+N_c+N_u-1]_{\text{below pinch}}$$

Where N_h = No. of hot streams

N_c = No. of cold streams

N_u = no. of utility streams

2.1.3.6.3 ESTIMATION OF HEN CAPITAL COST TARGET:

The target for the minimum surface area (A_{min}) and minimum no. of units can be added together with the heat exchanger cost law to determine the total capital cost (C_{HEN}). The capital cost is annualized using annualization factor.[19]

$$C_{HEN} = [N_{min}\ \{a+bx(A_{min}/N_{min})^{c}\}]_{\text{above pinch}} + [N_{min}\ \{a+bx(A_{min}/N_{min})^{c}\}]_{\text{below pinch}}$$

2.1.3.7 SUPERTARGETING:

To calculate optimum value of ΔT_{min} the total annual cost (TAC) of heat exchanger network (which is the sum of operating cost and capital cost) is plotted against the $\Delta T_{min.}$ Increase in ΔT_{min} value result in higher energy cost and lower capital cost and decrease in ΔT_{min} values result in lower energy cost and higher capital costs. So optimum corresponds the lowest value of ΔT_{min} at which total cost increases.[19]

2.1.3.8 DESIGN OF HEAT EXCHANGER NETWORK

The design of Heat exchanger network is accomplished by using the “pinch design method (PDM)”. This method incorporates with two important features.[25]

1. PDM recognised that pinch region is the most constraint part of the problems and as a result it start the design at pinch and carried out by moving away from this.
2. Pinch design method allows the designer to choose between match points

This method also applies tick off heuristic to identify the heat loads on pinch heat exchanger. Since pinch divides the heat exchanger network into two independent region and it been designed separately.

2.1.4 ADVANTAGES OF PINCH TECHNOLOGY:

1. Pinch reduces the energy consumption by improving its design.
2. Pinch reduces the energy cost due to reduction in energy consumption.
3. Pinch defines the energy and capital cost target ahead of design for individual process or the whole plant.[20]
4. Pinch provides the practical target by taking practical constraint into consideration.
5. Pinch tells the system wise view of problem.
6. Pinch also helps to reduce combustion product by emission targeting.
7. In comparison to other design tool of HEN pinch technology requires detailed information like geometry, flow sheet structure etc.
8. Pinch technology provides the best combined heat and power generation system.

2.1.5 APPLICATION OF PINCH TECHNOLOGY:

1. Heat integration –Heat exchange network
2. Mass integration –Mass exchange network
3. Total site targeting
4. In refineries for Hydrogen management
5. Emission targeting
6. Debottlenecking and retrofitting
7. Combined heat and power generation system

2.2 BRIEF STUDIES OF WORK DONE ON DESIGN OF HEN

Nejad et al. [1] applied pinch technology over ammonia plant. They performed energy target by considering constant as well as variation in physical properties. Physical properties like heat capacity, density, viscosity, and thermal conductivity are functions of temperature; pinch technology uses it as constant from source to target temperature. When considering variation in physical properties composite curve look like a curve so they perform segmentation of stream better to show a composite curve with segmentation. While performing segmentation of stream it should be kept in mind that for hot stream segmentation should be lower temperature than its actual temperature to maintain the validity of conservation approach and for cold stream segmentation should be at higher temperature than its actual temperature. Pinch temperatures have been increased by 3^0C when performed segmentation. Hot utilities as well as cold utilities also increased by 23 % and 11 %

respectively. Area target also being performed which is also increased by 50 % when performing segmentation. At last an aggregation diagram also plotted to evaluate the distribution of specific heat capacities over the whole streams of network.

González et- al. [2] proposed the method of total cost target which is based on pinch technology for heat exchanger network. This paper provides a new method which includes the present target method as well as area of network and cost of pumping. Total annual cost is the sum of heat exchanger capital cost, cost of pumping cost of utilities and cost of electricity for pumping. The problem solved as non linear optimization case for a fixed minimum temperature difference (ΔT_{min}). Thus solution provided the optimum pressure drop as well as heat transfer coefficient of process stream. Two problems have been taken to show the capability of this targeting method. In this method some assumptions are taken into account:

1. Physical properties of streams are constant i.e. they are temperature independent.
2. Vertical heat transfer is considered.
3. Heat exchange being done in single phase.
4. Shell and tube heat exchanger are considered.
5. The ΔT_{min} and target utility are given.

Thus this method provide a trade-off between capital cost, utility cost and power requirement after minimizing the total annual cost.

Sangia et al. [3] described pinch technology method which is able to solve the problem which uses constraints. This method considers each of hot process streams and all of the cold process streams. In the previous method each stream belongs to only one of the group but now in this method each of the cold stream may be present more than one group so a factor is been used which is called “belonging fraction” which is expressed as how much a cold stream belongs to that group. After calculating the belonging fraction the final group being determined. This method is performed in four steps. First of all a stream cascade table was generated. In the second step break the overall problem into different group also streams are divided into different groups independently. First group are called free group which has particularly those streams which are not bound to any match constraint and later could be transferred to any of the group while other group streams can match within their group streams freely and could match with other group streams in specific conditions. For all of each groups stream cascade table was also generated as it is done in 1st step for the given overall problem. In 3rd step streams of the free group been distributed among the other constraint groups. In this step matching has been carried out and this step also shows heat availability/needed at different temperature level. Finally got the solution and examine the solution to check the possibility of sharing streams with constraint group An example has been taken to show the effectiveness of this method and get better results than that of Linnhoff and O‘young [25] for the same problem. In this paper constant physical properties have been considered.

Dipama et- al. [4] presented a genetic algorithm technique to carry out synthesis as well as optimization of given heat exchanger network. This proposed technique provide best heat exchanger network except this it also provide different heat exchanger network as per our required application. When avoid division of flow streams this method provide heat exchanger network topology. Uniqueness of this method is that it deals the distribution of heat load as well as heat exchanger network topology simultaneously without violating thermodynamic principle to provide maximum energy recovery. Thus this problem becomes a mixed integer linear programming (MILP) for optimization as well as synthesis of HEN to get optimal solution. For this method there all several assumptions: first of all heat exchanger are counter current type and heat capacity as well as heat transfer are temperature independent. No heat transfer across pinch point also segmentation of streams do not carried out. For this method an algorithm has been proposed. In this method they considered constant physical properties throughout the proposed method.

Allen et al. [5] proposed a method for design of heat exchanger network to get maximum heat recovery for given minimum temperature difference using pinch technology. And also by using genetic algorithm the total annual cost have been minimized for each heat exchanger network. At a given ΔT_{min} the total cost of heat exchanger network are the sum of heat exchanger minimized cost with the cost of hot utility and cost of cold utility. The total cost becomes the function of minimum temperature difference. The minimum temperature difference (ΔT_{min}) at which more economical heat exchanger network is obtained known as optimal solution of the problem. This method also considered constant physical properties.

Lin Sun et al. [6] synthesized a new method based on pinch technology for multipass heat exchanger network. Both counter current and co-current flow are considered in this multipass heat exchanger network. The composite curve and problem table algorithm for the co-current flow are modified and compared with counter current flow arrangement of multipass heat exchanger network. For energy-capital cost trade-off a suitable minimum temperature difference is considered to synthesize multipass heat exchanger network. The minimum temperature difference (ΔT_{min}) selected for this problem is 20 ^{0}C. It is clear that heat transfer is more in counter current than in co-current flow arrangement for the same problem. The value of minimum temperature difference (ΔT_{min}) and heat transfer area for multi pass heat exchanger lies between co-current and counter-current arrangement. They also considered constant physical properties.

Bandpy et al. [7] presented a new method which is based on sequential quadratic programming and genetic algorithm for optimization of heat exchanger network. This proposed method solved the problem in two steps. In first step genetic algorithm distinguished the structure of optimized network. In the second step optimized thermal load of heat exchanger is determined through the sequential quadratic programming. To show the effectiveness of proposed method two heat exchanger network problems have been solved. An actual industrial problem of aromatic unit has been taken to show the applicability of this method. The result obtained from proposed optimization algorithm is better than those obtained from pinch analysis method and mathematical method for given heat exchanger network.This method also uses constant physical properties.

Colberg et al. [8] Utility targeting model is solved as linear programming model with the application of problem table algorithm. Linnhoff et al. 1978 performed no. of unit target by MILP. IN this paper these methods have been revived to performed area and cost targeting as NLPs. With the help of non linear programming the equilibrium between number of units and area of heat exchanger network have been calculated. Solutions of non linear programming provide temperature profiles which are almost similar to composite curves and the model gives almost ideal profile for heat exchanger network which attains area and capital cost target as well as utility target. Stream matches with their corresponding heat duty should be done properly to get minimum area as well as capital cost. These matches almost lead within few percent of area and cost target keeping equal number of heat exchanger in heat exchanger network as similar in the solution of non linear programming. The trade-off between area and the number of units should be evaluated with the prescribed non linear programming method. This non linear programming method handle completely non counter current stream matching likewise they can handle unequal heat transfer coefficient and a lot of hot and cold process streams. They also considered constant physical properties.

Panjeshahi et al. [9] described that debottlenecking could be applied on any unit or entire plant in process industries due to work load or change in process. This paper is basically concerned with pressure optimization. Many researchers have considered pressure optimization while designing heat exchanger network. Since energy consumption contribute huge sum of money in the total annual cost of process industries that is main driving force for the researchers. This paper deals with minimum total annual cost for the design of heat exchanger network for optimum debottlenecking. Debottleneck should be considered best if it enables to avoid purchasing of additional costly equipment like compressors, furnaces etc with improve designing of heat recovery system. It is carried out in number of stages like targeting stage and the next one is synthesis of heat exchanger network. This work is basically a retrofit for debottlenecking of heat exchanger network. This new method of debottlenecking has been applied efficiently considering a problem of crude oil pre heat considering optimum pressure drop. They also considered constant physical properties.

Joda et al. [10] pointed out that for designing multi stream heat exchanger pinch technology is the best method. The major problem of the this methods is that they provide more individual multi stream heat exchanger (MSHE) sections than essential, corresponding to the enthalpy intervals on temperature vs. enthalpy diagrams or composite curves. Here they used a new methodology to optimize the entrance and exit point of each stream and also used genetic algorithm to find suitable fin for heat exchanger network. Total annual cost has been minimized to synthesize the MSHE. Important parameters to be determined from MSHE design are heat exchanger dimension (length, height and width), number of stream passages and stacking pattern. Complexity of heat transfer paths, which result from differences in physical properties as well as entering and exit temperatures of different streams, makes the MSHE design as one of the most difficult problems in heat transfer engineering. Due to the complexity of MSHEN it does not receive more academic attention than other topic. In this paper number of sections has been reduced. Finally a Genetic algorithm optimizer is used to find optimum type of secondary surfaces along with unifying the flow length of all streams per individual section and obtaining a unified height per all MSHE in different sections. Applying the new design procedure in two industrial problem studies, 11% and 7% reductions in cost compared to the current method (by pinch technology) respectively by considering constant physical properties.

Jeżowski et al.[11] presented a method which calculates all pinches when there is a change in heat capacity within a certain limits with minimum cost of hot utility of heat exchanger networks (HEN). The disturbances are random and difficult to predict. Pinches play an important role in design of heat exchanger networks. A method had been presented when pinches changes its locations while operating the varying flow rates of process streams. This method is based on mixed-integer linear programming optimization. The change of process streams condition (such as capacity flow rate, temperature) took special attention towards researcher to optimize the HEN in such a situation. Several methods have been developed so for to get a flexible HEN that can withstand on varying conditions of process but were unable to give insight of problem. This paper overcomes this problem. This optimization technique took minimum number of runs to get all possible pinch locations. In this paper shifted temperature scale is being used for designing minimum utility cost heat exchanger networks by considering constant physical properties.

Bakar et al. [12] proposed application of model-based methodology in solving integrated process design and control (IPDC) of heat exchanger networks (HEN) has been presented. But in almost every paper the main emphasis is on total cost. Process operation issue is not considered specially control. In this paper its main focus on controllability. This paper developed a new model-based integrated process design and control methodology, which includes cost optimality and controllability aspects at the early HEN design stage. A heat exchanger network (HEN) is considered optimally operated if the target temperatures are satisfied at steady state (main objective), the utility cost is minimized (secondary goal), and the dynamic behaviour and control aspects are satisfactory (tertiary goal). It is expected that target at the pinch point will show better dynamics and controllability performance compared to the below and above pinch point by considering constant physical properties.

Matijaševiæ et al. [13] applied pinch technology on nitric acid plant and performs energy targeting as well as cost targeting. The plant produces 150 ton per day of nitric acid. In this problem study there are seventeen heat exchanger and two turbines and also two compressors. The energy produce by turbine is consumed by compressors. This paper shows that after applying pinch technology we were able to reduce the cooling water as well as medium pressure steam. Problem studied in this paper is basically a threshold problem where there is a need of only cooling utilities. There is no need of any heating utilities. The total number of heat exchanger also being reduced and three of them redesigned. There is also decrement in energy consumption and payback time comes around 14.5 month using pinch technology by considering constant physical properties.

Ravagnani et al. [14] described that optimization model considering pressure drop, fouling and many other parameter like bundle diameter, tube length, baffles and allocation of fluid etc. of shell & tube heat exchanger. For the synthesis of heat exchanger network they used decomposition method. For optimization they consider energy, area and pumping cost of heat exchanger network. The decomposition method consist of two parts one is dealt with MINLP superstructure and simultaneously optimizing HEN synthesis based on splitting of streams and MINLP model for designing of equipment using TEMA standard. In this paper heat exchanger network is synthesize by considering constant physical properties and also assuming the chances of splitting of streams. After designing the equipment heat transfer coefficient for each stream has been calculated. Again with this new value of heat transfer coefficient a new heat exchanger network is generated and this structure is compare with the previous one. If it is not similar with previous one then again HEN equipment is designed and the annual cost being evaluated. The heat transfer coefficient recalculated and objective is tested. If it is smaller than the previous one then it must be stop if not then continue until it meets our goal. We select that HEN which has low annual cost. Often no algorithm provides best result when we assume stream splitting.

Ebrahim et al. [15] asserted that pinch technology proved to be the best and simple method in the field of process integration. Pinch technology is based on basic thermodynamic principle which uses its basic laws. This gives us clear picture and overall view of the plant of consuming energy. This technology was developed by Linnhoff et-al [16] at ICI to design the HEN efficiently. This technology carried energy target, area target, number of unit target, shell target and in last cost target ahead of actual design. In designing we meet this target which we have done before. This technology was used initially in the grass root design but later on it extends its field to retrofitting also. For energy target we made grand composite curve in which at y axis we kept temperature and x axis enthalpy of process streams. After that we made grid diagram to fix the position of utilities. They perform pinch analysis by considering constant physical properties.

Linnhoff et al.[16] shows balance between energy and capital is a complex phenomenon in the design of heat exchanger network so while designing it is kept in mind that we should reduce total global cost as much as possible by reducing energy or number of heat exchanger etc.. In heat exchanger network there is possibility of different structure which create problem in keeping balance between energy and capital while designing. They have to find out minimum energy network in different network. In this paper researcher said that for HEN no general technique had been introduced to predict global optimum cost. This paper basically based on cost target and optimizes it prior to design. In the design of heat exchanger network minimum temperature difference plays an important role because when we change it utilities also affected which in turn changes area as well as number of heat exchanger. While dealing with these complexities designer continuously optimize all possible networks. The value of ΔT_{min} is completely based on the experience of designer to keep balance between energy and capital. Hohmann give the procedure to calculate minimum area for a fixed driving force by stream splitting while assuming constant heat transfer coefficient. In composite curve if we consider vertical heat transfer it lead us to minimum heat exchanger area. This paper deals frequently optimization of network before designing. The design technique presented in this paper is systematic. The approach presented here to tackle the problem is a practical one even for large problem. This paper tells us how to use remaining problem analysis technique.This paper deals by considering constant physical properties.

CHAPTER 3

PROBLEM STATEMENT

3.1 Problem 1

It comprises two hot and two cold streams viz H1, H2, C1 and C2. Also it has one hot utility and one cold utility.

Table 3.1 Stream Data for Problem-1 (constant CP)

Streams	**T_S**	**T_t**	**CP**	**h**
	K	**K**	**MW/K**	**MW/K-m^2**
H1	395	343	0.032433	0.00028
H2	405	288	0.021530	0.00025
C1	293	493	0.024508	0.00018
C2	353	383	0.040847	0.00022
Hot utility	521	520		0.00095
Cold utility	278	288		0.00070

Heats capacities as a function of temperature of above four streams are given below where unit of CPs are MW/K.

CP_{H1}=0.02228-3.03095x10^{-5}xT-6.58613x10^{-9}xT^2+4.4252x10^{-10}xT^3

CP_{H2}=0.015354+9.50642x10^{-6}xT+2.40084x10^{-8}xT^2

CP_{C1}=0.025032-5.29916x10^{-5}xT+1.31445x10^{-7}xT^2

CP_{C2}=0.042727-37.4643x10^{-5}xT+2.79584x10^{-6}xT^2-8.6649x10^{-9}xT^3+1.03158x10^{-11}xT^4

3.2 Problem 2

It comprises two hot and two cold streams viz H1, H2, C1 and C2. Also it has one hot utility and one cold utility.

Table 3.2 Stream Data for Problem-2 (constant CP)

Stream	**T_S**	**T_t**	**CP**	**h**
	K	**K**	**MW/K**	**MW/K-m^2**
H1	413	323	0.020094	0.00025
H2	363	313	0.024109	0.00015
C1	303	423	0.028014	0.00021
C2	343	398	0.031643	0.00027
Hot utility	523	522		0.00085
Cold utility	283	293		0.00072

Also heats capacities as a function of temperature of above four streams is given below, where unit of CPs are MW/K.

$CP_{H1}=0.013958+8.6422x10^{-6}xT+2.18258x10^{-8}xT^2$

$CP_{H2}=0.017270+2.73302x10^{-6}xT+5.178x10^{-8}xT^2$

$CP_{C1}=0.015314+9.78098x10^{-6}xT+6.94372x10^{-8}xT^2$

$CP_{C2}=0.020379+18.8036x10^{-6}xT+3.12988x10^{-8}xT^2$

3.3 Problem 3

This problem is taken from sponge Iron industry. It is the metallic form of iron which is produced by the reduction of iron oxide below the fusion temperature of iron ore (1535 ^{0}C) by utilizing hydrocarbon gases or carbonaceous fuels as coal [26]. In last few years it is seen that the growth of sponge iron industry is unremarkable and today India is the largest producer of sponge iron as it covers 16% of global output. The structure is like ‘honeycomb’, due to this it is named as sponge iron. As the iron ore is in direct contact with the reducing agent throughout the reduction process, it is often termed as direct reduced iron (DRI).

The given problem comprises of four hot and four cold streams in which H1 stream is sponge iron, H2, H3 and C3 are carbon gases, H4 and C1 is waste gas which is mixture of flue gases. C2 is the magnetite which is the ore of iron and C4 is the air.

Table 3.3 Stream Data for Problem-3 (constant CP)

Streams	**T_S**	**T_t**	**CP**
	K	**K**	**MW/K**
H1	1293	383	0.005290
H2	353	303	0.001419
H3	493	303	0.001584
H4	493	395.4	0.047738
C1	333	415.7	0.047891
C2	303	393	0.008690
C3	303	393	0.001958
C4	303	573	0.025325

Also heat capacities as a function of temperature of above eight streams of sponge iron plant is given below, where unit of CPs are kW/K.

$CP_{H1} = 4.851128 + 5.735248 \times 10^{-4}\ T - 29291.28/T^2$

$CP_{H2} = 1.5522 + 1.5197 \times 10^{-3}\ T - 67883.83/\ T^2$

$CP_{H3} = 1.422036 + 1.3922 \times 10^{-3}\ T - 62190.8/\ T^2$

$CP_{H4} = 43.172 + 7.415 \times 10^{-3} \times T + 8.292 \times 10^{-6} \times T^2 - 4.18 \times 10^{-9}\ T^3$

$CP_{C1} = 43.172 + 7.415 \times 10^{-3} \times T + 8.292 \times 10^{-6} \times T^2 - 4.18 \times 10^{-9}\ T^3$

$CP_{C2} = 8.014 + 5.2 \times 10^{-3}\ T - 137262.8928/\ T^2$

$CP_{C3} = 1.99905 + 1.9572 \times 10^{-3}\ T - 87426.003/\ T^2$

$CP_{C4} = 22.94 + 3.94 \times 10^{-3} \times T + 4.41 \times 10^{-6} \times T^2 - 2.22 \times 10^{-9}\ T^3$

CHAPTER 4

SOLUTION TECHNIQUES

To study the heat integration of heat exchanger network lot of methods are present but every method consider constant physical property. Pinch technology has been consider to show the dependency of temperature of process streams by performing targeting and then these targeted values are met in design stage. These things are carried out in sequential manner in different steps. These steps are follows:

1. First a HEN problem has been taken.
2. Search the data of the problem given.
3. Select initial value of ΔT_{min}.
4. Carry out energy targeting of the problems to get the minimum hot and cold utility by graphical as well as with Problem table algorithm.
5. Carry out no. of unit target of given problem.
6. Carry out area target to get the area of HEN of the given problem.
7. Carry out cost target of the given problem which is the total annual cost, which is the sum of annual operating and capital cost of HEN.
8. Carry out super targeting of HEN to get the optimum value of HEN.

At last design of HEN is being performed by meeting the above targeted values.

CHAPTER 5

RESULTS AND DISCUSSIONS

This chapter deals with the results, which is obtained by pinch analysis while considering constant and variation in physical property. Three problems have been taken two shows the temperature dependency of streams. For this first of all targeting has been done and in the designing these target are met. It provides a trend in energy as well as area targeting for the problems taken. Pinch analysis provides close result before actual design is being performed.

5.1 ENERGY TARGETING

5.1.1 Problem 1

It comprises two hot and two cold streams namely H1, H2 and C1, C2 along with one external hot and cold utility. Stream data for problem 1 is given in Table 3.1 and considering ΔT_{min} = 10 K. For this Problem, Problem table algorithm is generated in table 5.1 and 5.2 while considering constant and variation in physical properties. A comparison Table between utilities is also presented in Table 5.3 while considering constant and variation in CP.

Problem table algorithm is generated to get the minimum hot and cold utility. From table 5.1 it is seen that minimum hot and cold utility comes 2.7144 MW and 0.79293 MW and pinch temperature is 358 K while considering constant CP. From table 5.2 when consider variation in CP hot and cold utility comes 2.98958 MW and 0.84797 MW and pinch temperature is 358 K. There is an increase of hot and cold utilities by 10.14 % and 6.94 % respectively. Pinch temperature remains unaffected.

GCC for both the cases are presented in fig 5.1 and fig 5.2 which also clearly show these increment in utility and there is no change in pinch temperature for both the cases, which is 358 K.

Table 5.1 Problem Table Algorithm for Problem- 1 (Constant CP)

Temperature	**∑(CP)$_c$-∑(CP)$_h$**	**Q_{int}**	**Q_{cas}**	**R_{cas}**
K	MW/K	MW	MW	MW
498	0	0	0	2.71441
400	0.02451	2.40178	-2.40178	0.31263
390	0.00298	0.02978	-2.43156	0.28285
388	-0.02946	-0.05891	-2.37265	0.34176
358	0.01139	0.34176	-2.71441	0.00000
338	-0.02946	-0.58910	-2.12531	0.58910
298	0.00298	0.11912	-2.24443	0.46998
283	-0.02153	-0.32295	-1.92148	0.79293

Table 5.2 Problem Table Algorithm for Problem- 1 (Variable CP)

Temperature	**∑(CP)$_c$-∑(CP)$_h$**	**Q_{int}**	**Q_{cas}**	**R_{cas}**
K	MW/K	MW	MW	MW
498			0.00000	2.98958
400	0.02784	2.72861	-2.72861	0.26097
390	0.00176	0.01755	-2.74616	0.24342
388	-0.03392	-0.06784	-2.67833	0.31125
358	0.01038	0.31125	-2.98958	0.00000
338	-0.02866	-0.57312	-2.41646	0.57312
298	0.00068	0.02728	-2.44374	0.54584
283	-0.02014	-0.30213	-2.14161	0.84797

Table 5.3 Energy Targeting with constant and variable CP for Problem- 1

	ΔT_{min} (K)	Pinch Temperature (K)	hot utility (MW)	cold utility (MW)
Constant CP	10	358	2.71441	0.79293
Variable CP	10	358	2.98958	0.84797

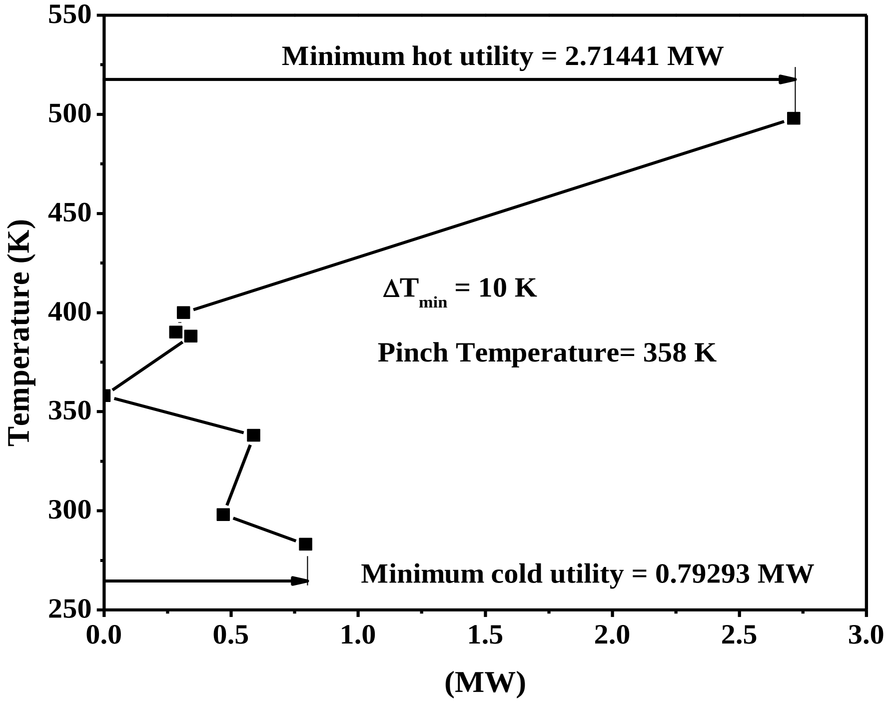

Figure 5.1 Grand composite Curve for problem 1 (Constant CP)

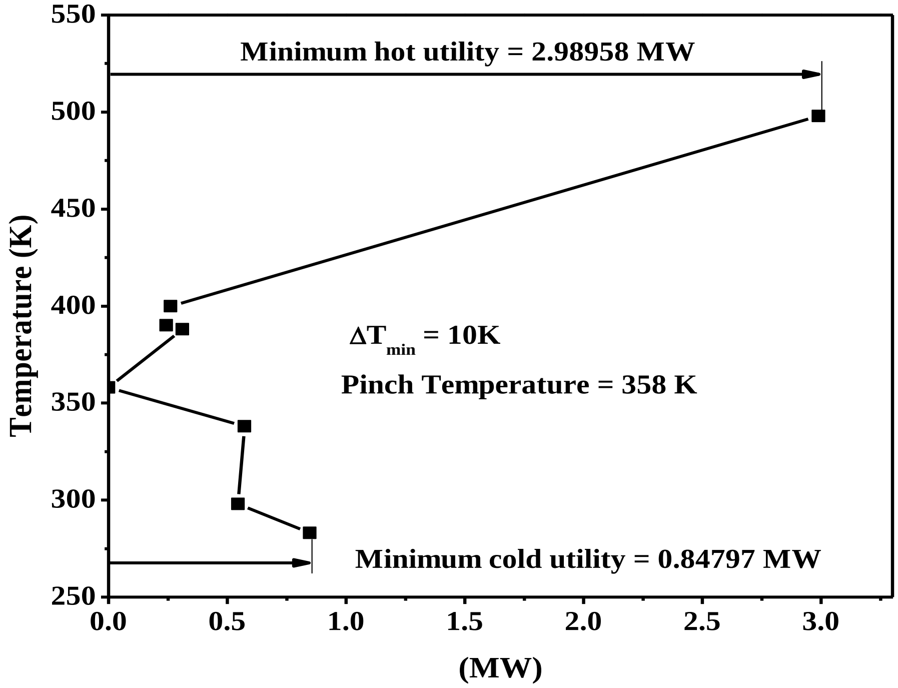

Figure 5.2 Grand composite Curve for problem 1 (Variable CP)

5.1.2 Problem 2

It comprises two hot and two cold streams namely H1, H2 and C1, C2 along with one external hot and cold utility. Stream data for problem 2 is given in Table 3.2 and considering ΔT_{min} = 10 K. For this Problem, Problem table algorithm is generated in table 5.4 and 5.5 while considering constant and variation in physical properties. A comparison Table between utilities is also presented in Table 5.6 while considering constant and variation in CP.

Problem table algorithm has been generated to get the minimum hot and cold utility. From table 5.4 it is seen that minimum hot and cold utility comes 2.5348 MW and 0.4466 MW and pinch temperature is 348 K while considering constant CP. From table 5.5 when consider variation in CP hot and cold utility comes 2.6524 MW and 0.4874 MW and pinch temperature is 348 K. There is a increase of hot and cold utilities by 4.64 % and 9.14 % respectively. Pinch temperature remains unaffected.

GCC for both the cases are presented in fig 5.3 and fig 5.4 which also clearly shows these increment in utility and there is no change in pinch temperature for both the cases, which is 348 K.

Table 5.4 Problem Table Algorithm for Problem- 2 (Constant CP)

Temperature	**$\sum(CP)_c-\sum(CP)_h$**	**Q_{int}**	**Q_{cas}**	**R_{cas}**
K	MW/K	MW	MW	MW
428	0	0	0	2.5348
408	0.028014	0.56028	-0.56028	1.9745
403	0.00792	0.0396	-0.59988	1.9349
358	0.039563	1.780335	-2.38022	0.1546
348	0.015454	0.15454	-2.53476	0.0000
318	-0.01619	-0.48567	-2.04909	0.4857
308	0.003905	0.03905	-2.08814	0.4466

Table 5.5 Problem Table Algorithm for Problem- 2 (Variable CP)

Temperature	**$\sum(CP)_c-\sum(CP)_h$**	**Q_{int}**	**Q_{cas}**	**R_{cas}**
K	MW/K	MW	MW	MW
428	0	0	0	2.6524
408	0.031537	0.63074	-0.63074	2.0217
403	0.009647	0.048235	-0.678975	1.9735
358	0.040761	1.834245	-2.51322	0.1392
348	0.013921	0.13921	-2.65243	0.0000
318	-0.01691	-0.50721	-2.14522	0.5072
308	0.00198	0.0198	-2.16502	0.4874

Table 5.6 Energy Targeting with constant and variable CP for Problem- 2

	ΔT_{min} (K)	Pinch Temperature (K)	hot utility (MW)	cold utility (MW)
Constant CP	10	348	2.5348	0.4466
Variable CP	10	348	2.6524	0.4874

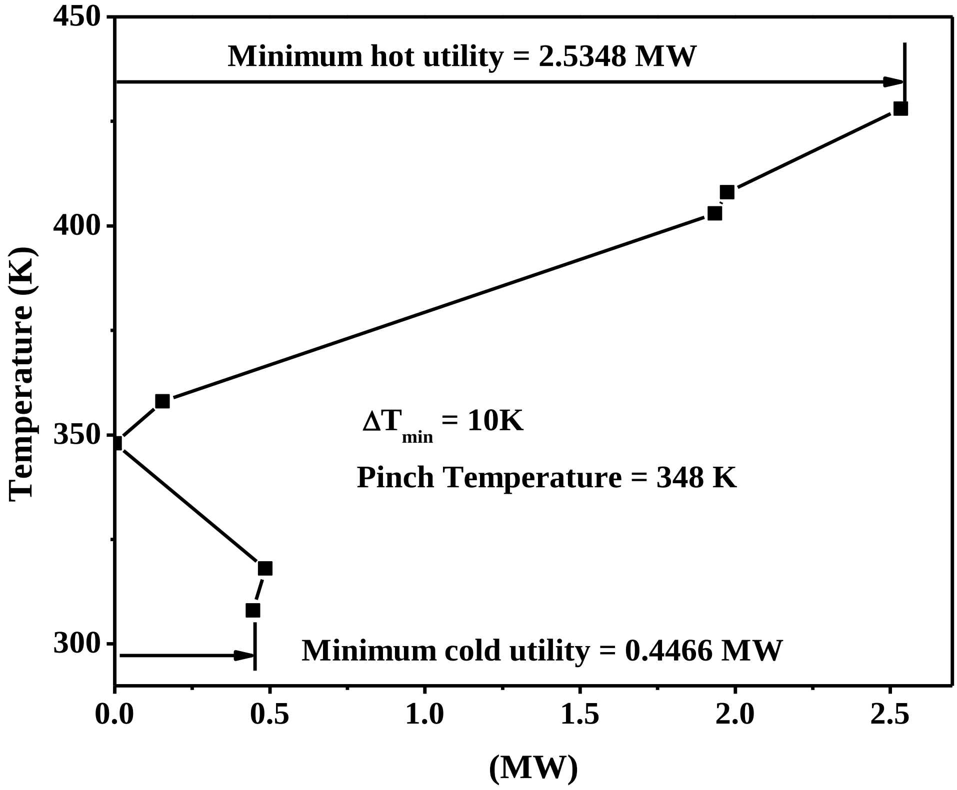

Figure 5.3 Grand composite Curve for problem 2 (Constant CP)

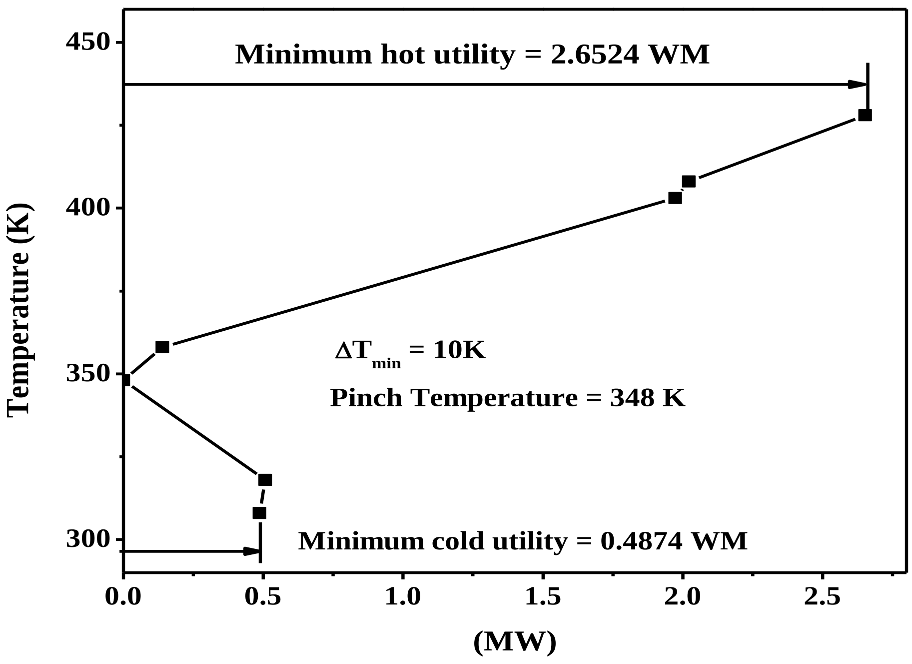

Figure 5.4 Grand composite Curve for problem 2 (Variable CP)

5.1.3 Problem 3

It comprises four hot and four cold streams alongwith one external hot and cold utility. Stream data for problem 3 is given in Table 3.3 and considering ΔT_{min} = 40 K for Problem 3. For this Problem, Problem table algorithm is generated in table 5.7 and 5.8 while considering constant and variation in physical properties. A comparison Table between utilities is also presented in Table 5.9 while considering constant and variation in CP.

Problem table algorithm has been generated to get the minimum hot and cold utility. From table 5.7 it is seen that minimum hot and cold utility comes 2.0574 MW and 0.12 MW and pinch temperature is 348 K while considering constant CP. From table 5.8 when consider variation in CP hot and cold utility comes 2.198 MW and 0.0.0972 MW and pinch temperature are 323 K. There is an increase of 6.83 % in hot and decrease of 19 % in cold utillities and Pinch temperature remains unaffected.

GCC for both the cases are presented in fig 5.5 and fig 5.6 which also clearly shows these increament in utility and there is no change in pinch temperature for both the cases, which is 323 K.

Table 5.7 Problem Table Algorithm for Problem- 3 (Constant CP)

Temperature	**$\sum(CP)_c$-$\sum(CP)_h$**	**Q_{int}**	**Q_{cas}**	**R_{cas}**
K	MW/K	MW	MW	MW
1273	0	0	0.000000	2.0574
593	-0.00529	-3.5972	3.597200	5.6546
473	0.020035	2.4042	1.193000	3.2504
435.7	-0.02929	-1.092517	2.285517	4.3429
413	0.018603	0.4222881	1.863229	3.9207
375.94	0.029252	1.08407912	0.779150	2.8366
363	0.076991	0.99626354	-0.217114	1.8403
353	0.082281	0.82281	-1.039924	1.0175
333	0.03439	0.6878	-1.727724	0.3297
323	0.03297	0.3297	-2.057424	0.0000
283	-0.003	-0.12	-1.937424	0.1200

Table 5.8 Problem Table Algorithm for Problem- 3 (Variable CP)

Temperature	**$\sum(CP)_c-\sum(CP)_h$**	**Q_{int}**	**Q_{cas}**	**R_{cas}**
K	MW/K	MW	MW	MW
1273			0	2.1980
593	-0.00535	-3.638	3.638	5.8360
473	0.02091	2.5092	1.1288	3.3268
435.7	-0.02915	-1.087295	2.216095	4.4141
413	0.01964	0.445828	1.770267	3.9683
375.94	0.03097	1.1477482	0.6225188	2.8206
363	0.0774	1.001556	-0.3790372	1.8190
353	0.0819	0.819	-1.1980372	1.0000
333	0.03391	0.6782	-1.8762372	0.3218
323	0.03218	0.3218	-2.1980372	0.0000
283	-0.00243	-0.0972	-2.1008372	0.0972

Table 5.9 Energy Targeting with constant and variable CP for Problem- 3

	ΔT_{min} (K)	Pinch Temperature (K)	hot utility (MW)	cold utility (MW)
Constant CP	40	323	2.0574	0.1200
Variable CP	40	323	2.1980	0.0972

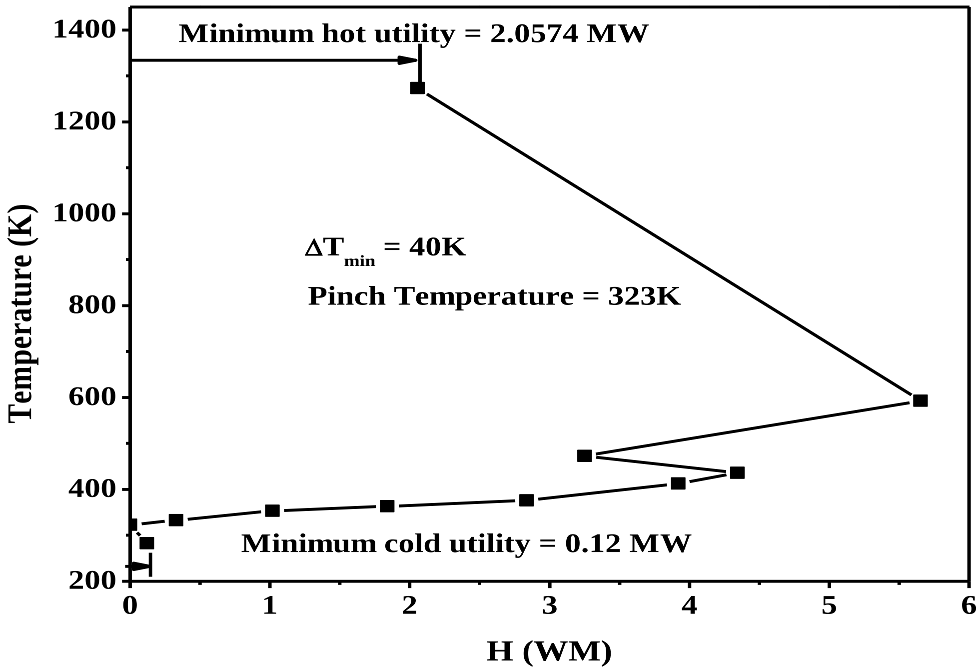

Figure 5.5 Grand composite Curve for problem 3 (Constant CP)

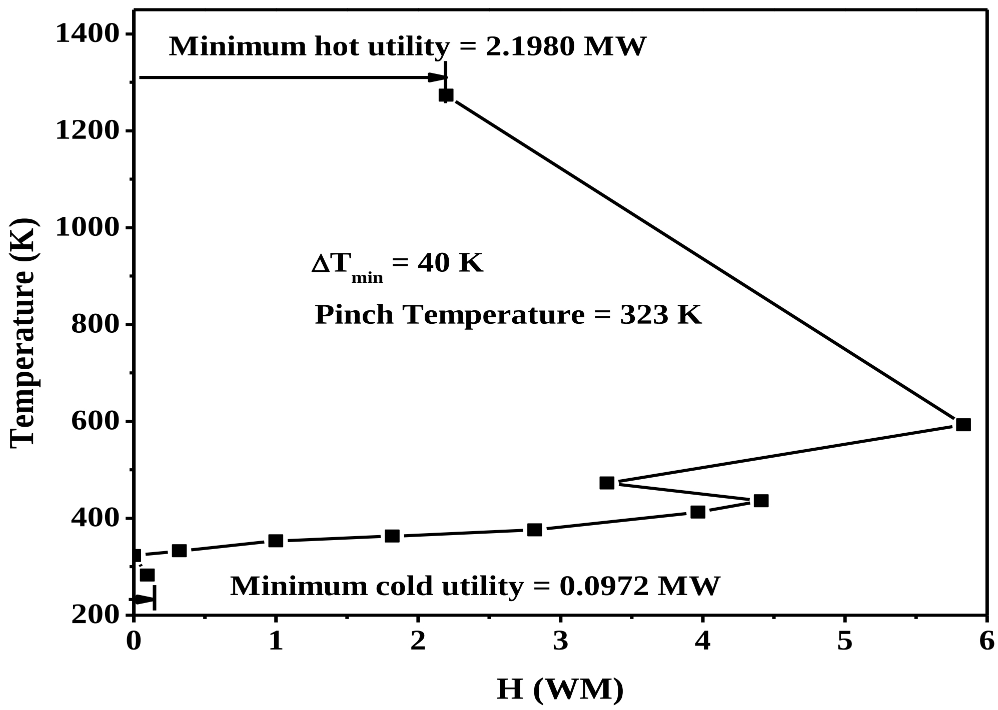

Figure 5.6 Grand composite Curve for problem 3 (Variable CP)

5.2 NUMBER OF UNIT TARGETING

5.2.1 Problem 1

Table 5.10 No. of unit targeting with constant and variable CP for Problem- 1

	ΔT_{min} (K)	Pinch Temperature (K)	No. of units
Constant CP	10	358	7
Variable CP	10	358	7

5.2.2 Problem 2

Table 5.11 No. of unit targeting with constant and variable CP for Problem- 2

	ΔT_{min} (K)	Pinch Temperature (K)	No. of units
Constant CP	10	348	7
Variable CP	10	348	7

5.2.3 Problem 3

Table 5.12 No. of unit targeting with constant and variable CP for Problem- 3

	ΔT_{min} (K)	Pinch Temperature (K)	No. of units
Constant CP	40	323	10
Variable CP	40	323	10

From table 5.10 it is seen that pinch temperature are constant in both the cases which is 358 K so no. of unit does not in both the cases. Table 5.11 shows no change in pinch temperature therefore no change in no. of unit. From table 5.12 it is seen that pinch temperature are constant in both the cases which is 323 K so no. of unit does not in both the cases. Therefore if pinch temperature does not change then no. of unit also not change.

5.3 AREA TARGETING

5.3.1 Problem 1

Area target of problem 1 has been done for both cases such as considering constant and variable CP of problem and calculation table are shown in table A-5 and A-6 also BCC curve are shown below in fig. 5.7 and 5.8. It is clear from fig 5.7 and 5.8 cum Q is increases when considering variable CP due to this area decreases. It is evident from the following table 5.13 that considering variable CP the area of HEN is decreased by 5.95 %.

Table 5.13 Area Targeting with constant and variable CP for Problem- 1

	ΔT_{min} (K)	Pinch Temperature (K)	Area (m^2)
Constant CP	10	358	2384.74 0.77093
Variable CP	10	358	2242.82 0.84797

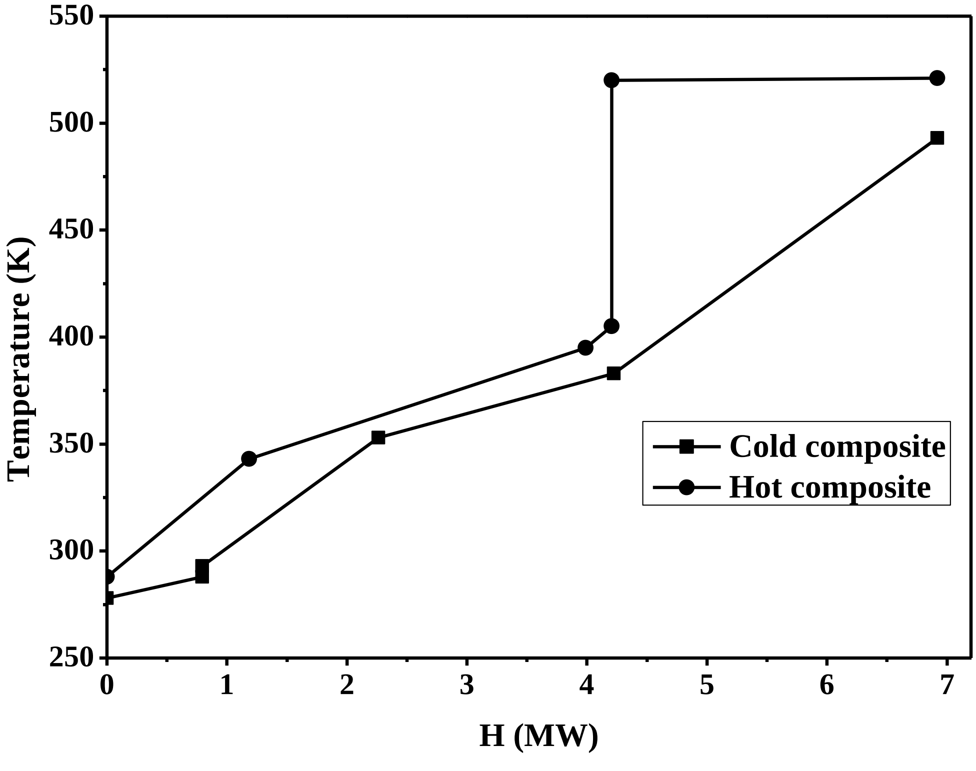

Figure 5.7 Balance Composite Curve for problem 1 (Constant CP)

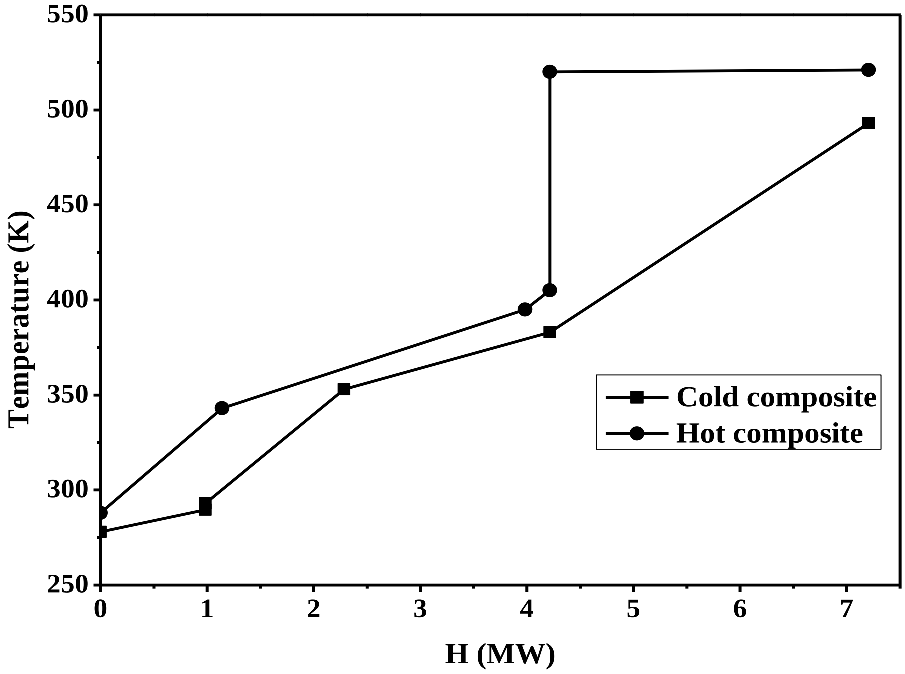

Figure 5.8 Balance Composite Curve for problem 1 (Variable CP)

5.3.2 Problem 2

Area target of problem 2 has been done for both cases such as considering constant and variable CP of problem and calculation table are shown in table A-7 and A-8 also BCC curve are shown below in fig. 5.9 and 5.10. It is clear from fig 5.7 and 5.8 cum Q is increases when considering variable CP due to this area decreases. It is evident from the following table 5.14 that considering variable CP the area of HEN is decreased by 11.24 %.

Table 5.14 Area Targeting with constant and variable CP for Problem- 2

	ΔT_{min} (K)	Pinch Temperature (K)	Area (m^2)
Constant CP	10	348	1645.41 0.77093
Variable CP	10	348	1460.40 0.84797

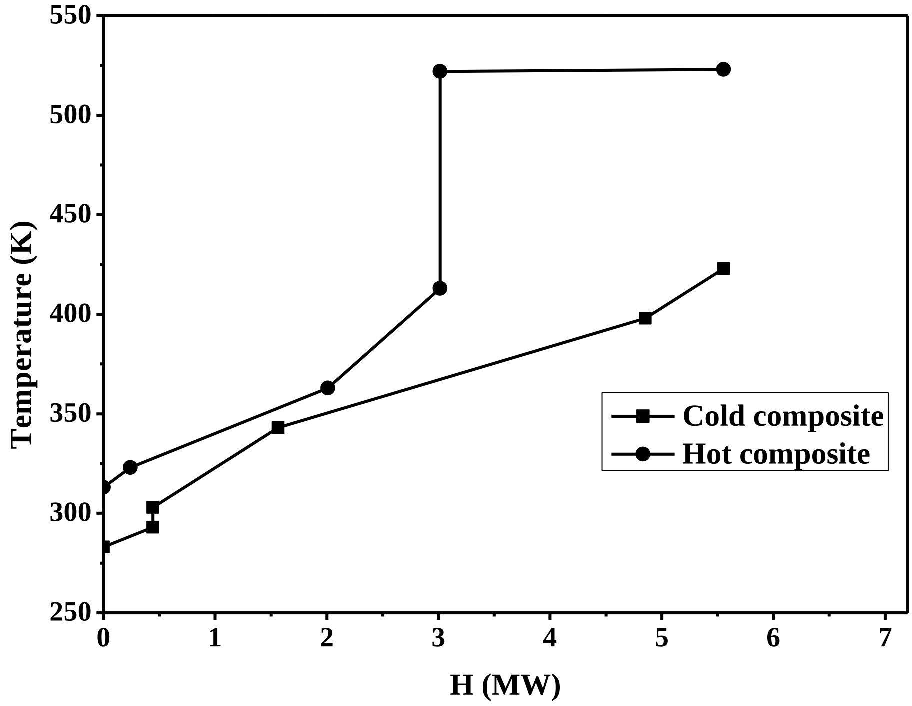

Figure 5.9 Balance Composite Curve for problem 2 (Constant CP)

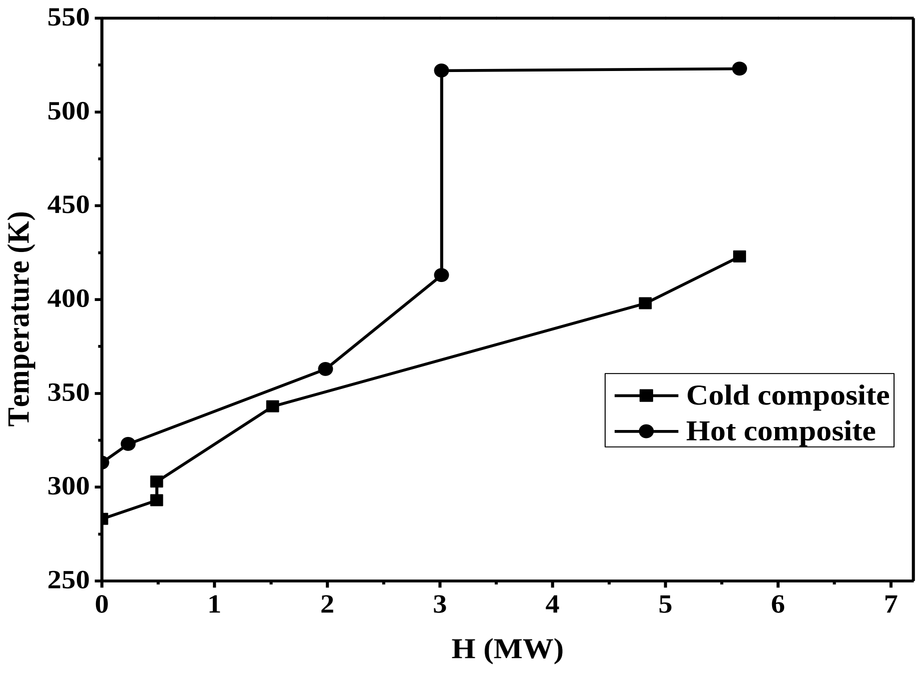

Fig 5.10 Balance Composite Curve for problem 2 (Variable CP)

5.4 COST TARGETING

Cost targeting of heat exchanger network have been done by using the following formula for the given problems while considering constant and variable CP.

Capital cost (CC) of heat exchanger network ($) = N (30000 + 750 x $(A/N)^{0.81}$)

Where A is the area of heat exchanger in m^2 and N is no. of units

n (useful life of heat exchanger) = 5yr

i (fractional interest rate per year) = 10 %

Annualization factor = $\frac{i \times (1+i)^n}{(1+i)^n - 1}$

Annualized capital cost (ACC) = capital cost x Annualization factor

Cost of hot utility (C_h) = 120,000 $ MW/yr

Cost of cold utility (C_c) = 10,000 $ MW/yr

Q_h = hot utility (MW)

Q_c = cold utility (MW)

Annual operating Cost (AOC) $ = Q_h x C_h + Q_c x C_c

Total annual Cost (TAC) = Annualized capital cost + Annual operating cost

5.4.1 Problem 1

Cost targeting has been done for this problem considering constant and variable CP and results are given in table 5.15. It is shown that considering variable CP annual capital cost decreases by 3.57 % but annual operating cost increases by 10.06 %. The total annual cost increases by 4.77 % due to increase in consumption of external utility.

Table 5.15 Cost Targeting with constant and variable CP for Problem- 1

	Q_h	Q_c	A	CC	ACC	AOC	TAC
	MW	MW	m^2	$	$	$	$
Constant CP	2.71441	0.79293	2384.74	800686	211221	333658	**544879**
Variable CP	2.98958	0.84797	2242.82	772048	203666	367229	**570895**

5.4.2 Problem 2

Cost targeting has been done for this problem considering constant and variable CP and results are given in table 5.16. It is shown that considering variable CP annual capital cost decreases by 4.55 % but annual operating cost increases by 4.70 %. The total annual cost increases by 0.81 % due to increase in consumption of external utility.

Table 5.16 Cost Targeting with constant and variable CP for Problem- 2

	Q_h	Q_c	A	CC	ACC	AOC	TAC
	MW	MW	m^2	$	$	$	$
Constant CP	2.5348	0.4466	1645.41	647333	170766	308642	**479408**
Variable CP	2.6524	0.4874	1460.40	607056	160141	323162	**483303**

5.5 SUPERTARGETING

5.5.1 Problem 1

BCC data at different value of ΔT_{min} are shown in Table A-9 and A-11 at constant and variable CP in Appendix A. Energy targeting table at different value of ΔT_{min} are shown in the table 5.17 by considering constant and variation in CP. Area targeting table also shown at different value of ΔT_{min} in the table 5.18 by considering constant and variation in CP. To calculate optimum value of ΔT_{min} super targeting has been performed and results are tabulated in table 5.19.

Table 5.17 shows the change in utility as ΔT_{min} changes by 5 K when considering constant and variable CP. These utilities increase as ΔT_{min} increases at constant or variable CP. At the same ΔT_{min} value utilities are larger when consider variable CP.

Table 5.18 shows the change in area as ΔT_{min} changes by 5 K when considering constant and variable CP. The area decreases as ΔT_{min} increases at constant or variable CP. At the same ΔT_{min} value area are less when consider variable CP.

Table 5.19 shows the change in TAC as ΔT_{min} changes by 5 K when considering constant and variable CP. The TAC increases as ΔT_{min} increases at constant or variable CP. At the same

ΔT_{min} value TAC are larger when consider variable CP. So optimum ΔT_{min} is 10 K for both the cases.

Table 5.17 Energy Targeting with constant and variable CP for Problem- 1

ΔT_{min}	Hot utility		Cold utility	
	Constant CP	Variable CP	Constant CP	Variable CP
K	MW	MW	MW	MW
10	2.7144	2.9896	0.79293	0.8480
15	2.9842	3.3071	1.0628	1.0957
20	3.254	3.6254	1.3326	1.3434
25	3.5239	3.9444	1.6024	1.5912
30	3.7937	4.2643	1.8722	1.8393
35	4.0635	4.5850	2.142	2.0874
40	4.3333	4.9067	2.4118	2.3357
45	4.5148	5.1337	2.5933	2.4888
50	4.6373	5.2982	2.7159	2.5783

Table 5.18 Area Targeting with constant and variable CP for Problem- 1

ΔT_{min}	Constant CP	Variable CP
K	m^2	m^2
10	2384.74	2242.82
15	1806.17	1667.94
20	1483.02	1361.79
25	1277.83	1173.96
30	1137.47	1050.97
35	1037.71	961.47
40	964.35	906.14
45	925.80	874.95
50	903.33	858.36

Table 5.19 Super Targeting with constant and variable CP for Problem- 1

ΔT_{min}	Constant CP	Variable CP
	TAC	TAC
K	$	$
10	544878.4	570895.4
15	548546.8	579854.1
20	565259.6	602860.6
25	588294.3	632402.9
30	614913.2	665745.7
35	643857.3	701133.7
40	674352.2	738716.1
45	695514.5	765502.2
50	710013.7	785065.4

5.5.2 Problem 2

BCC data at different value of ΔT_{min} are shown in Table A-10 and A-12 at constant and variable CP in Appendix A. Energy targeting table at different value of ΔT_{min} are shown in the table 5.20 by considering constant and variation in CP. Area targeting table also shown at different value of ΔT_{min} in the table 5.21 by considering constant and variation in CP. To calculate optimum value of ΔT_{min} super targeting has been performed and results are tabulated in table 5.22.

Table 5.20 shows the change in utility as ΔT_{min} changes by 5 K when considering constant and variable CP. These utilities increase as ΔT_{min} increases at constant or variable CP. At the same ΔT_{min} value utilities are larger when consider variable CP.

Table 5.21 shows the change in area as ΔT_{min} changes by 5 K when considering constant and variable CP. The area decreases as ΔT_{min} increases at constant or variable CP. At the same ΔT_{min} value area are less when consider variable CP.

Table 5.22 shows the change in TAC as ΔT_{min} changes by 5 K when considering constant and variable CP. The TAC increases as ΔT_{min} increases at constant or variable CP. At the same ΔT_{min} value TAC are larger when consider variable CP. So optimum ΔT_{min} is 10 K for both the cases.

Table 5.20 Energy Targeting with constant and variable CP for Problem- 2

ΔT_{min}	Hot utility		Cold utility	
	Constant CP	Variable CP	Constant CP	Variable CP
K	MW	MW	MW	MW
10	2.5348	2.6524	0.4466	0.4874
15	2.7558	2.8963	0.6676	0.697
20	2.9768	3.1402	0.8887	0.9066
25	3.1169	3.2992	1.0287	1.0312
30	3.2569	3.4583	1.1688	1.1557
35	3.3970	3.6175	1.3089	1.2804
40	3.5371	3.7768	1.4489	1.405
45	3.6771	3.9361	1.5890	1.5297
50	3.8172	4.0956	1.7291	1.6544

Table 5.21 Area Targeting with constant and variable CP for Problem- 2

ΔT_{min}	Constant CP	Variable CP
K	m^2	m^2
10	1645.41	1460.4
15	1196.78	1081.87
20	962.03	874.23
25	862.05	786.62
30	786.76	721.63
35	728.66	672.84
40	683.13	635.64
45	647.08	606.22
50	618.13	584.48

Table 5.22 Super Targeting with constant and variable CP for Problem- 2

ΔT_{min}	Constant CP	Variable CP
	TAC	TAC
K	$	$
10	479403.8	483303
15	481911.7	492070
20	496193.6	510411
25	508050.1	525070
30	521382.9	541126
35	535768.3	558215
40	550940.4	576060
45	566717.5	594412
50	582955	613301

5.6 DESIGN OF HEN

5.6.1 Problem 1

For constant CP two designs are proposed in fig 5.11 and 5.12. In the design 1 two heaters are required one of duty 0.1878 MW and other one of 2.526 MW. The sum of both heater duties is equal to the required heating duty of 2.714 MW and cooler duty is 0.792 MW. In the design 2 one heater and one cooler is required of duty 2.714 MW and 0.792 MW respectively. So for constant CP design 2 are proposed because it meets the target and the designs are shown in fig. 5.12.

Also for variable CP two designs are proposed in fig 5.13 and 5.14. In the design 1 one heater is required of duty 2.7155 MW which is less than the required heating duty of 2.98958 MW and cooler duty is 0.7718 MW which is less than the required cooling duty of 0.84797 MW. In the design 2 one heater and one cooler is required of duty 2.774 MW and 0.7718 MW respectively. So for variable CP design 2 is proposed because it is closer to required duty. So the proposed design is under designed by 7.77 % and the designs are shown in fig. 5.14.

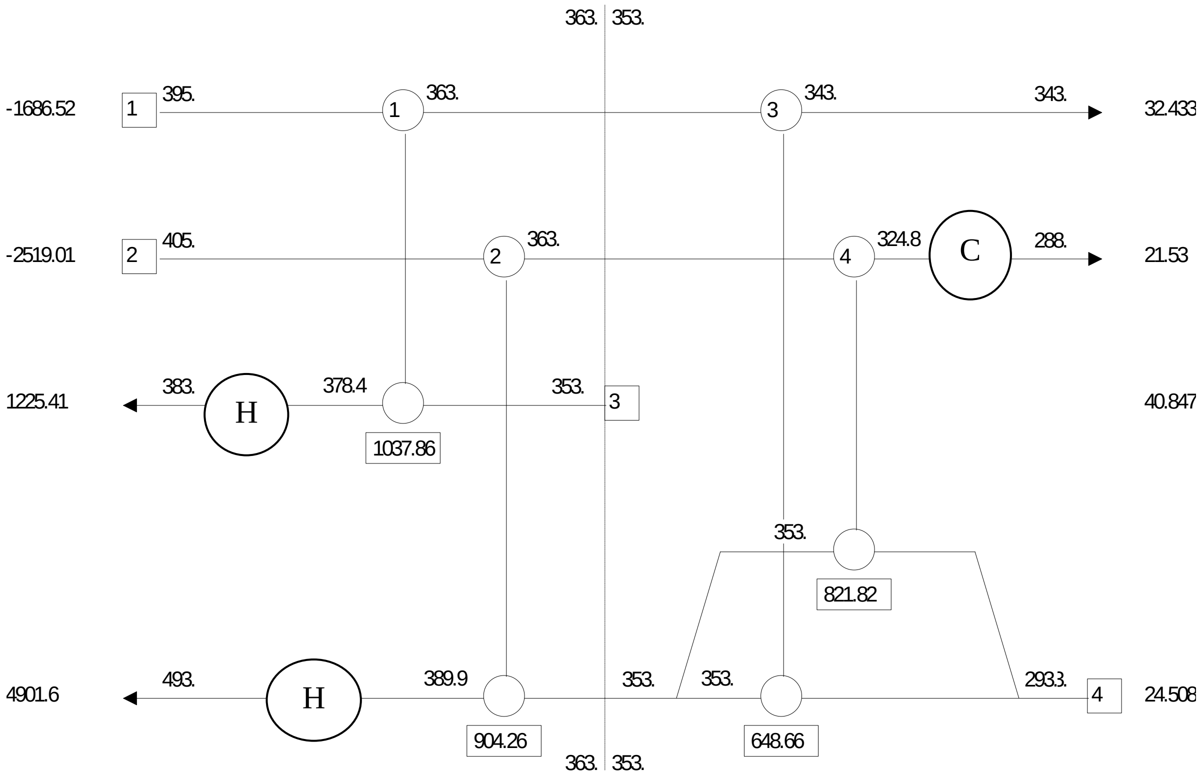

Fig 5.11 Design 1 of Problem 1 (Constant CP)

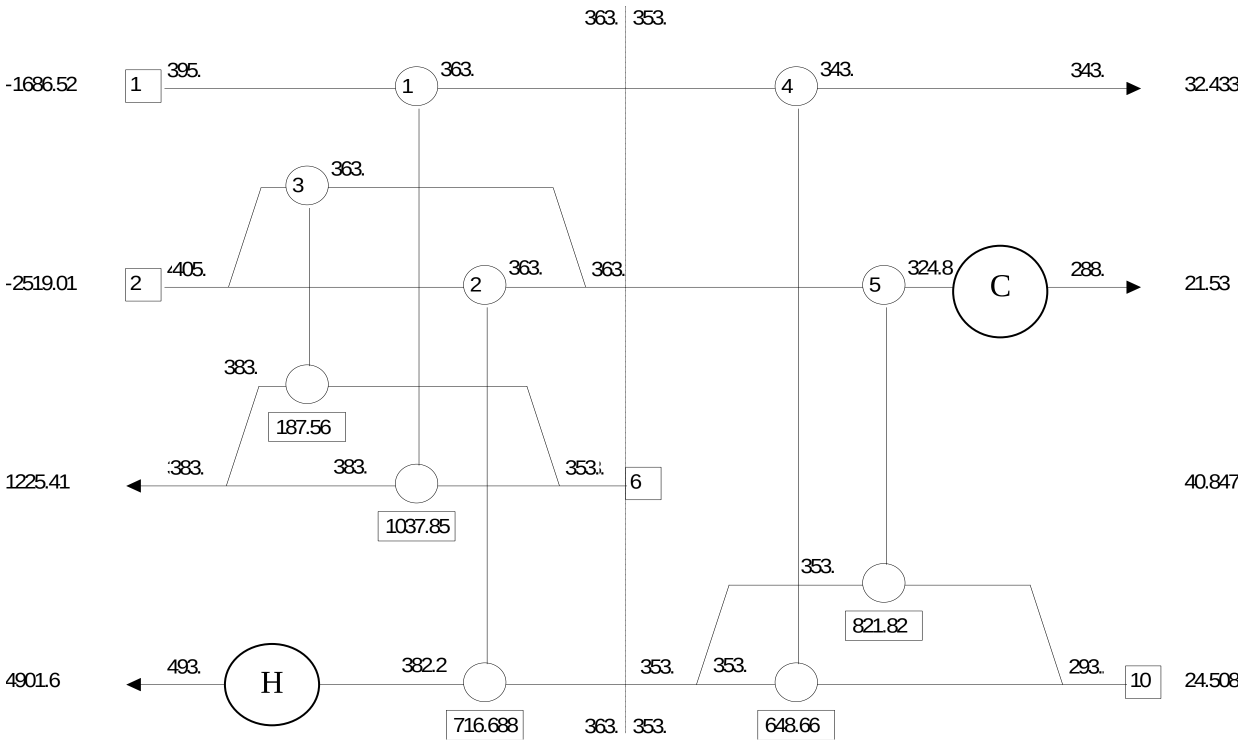

Fig 5.12 Design 2 of Problem 1 (Constant CP)

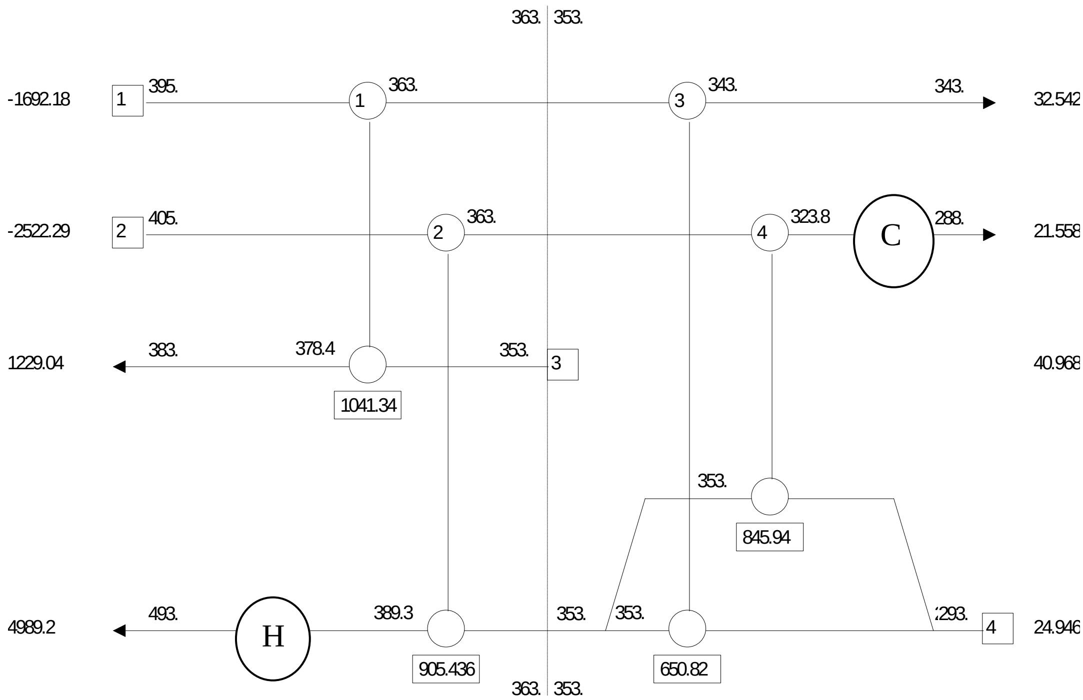

Fig 5.13 Design 1 of Problem 1 (Variable CP)

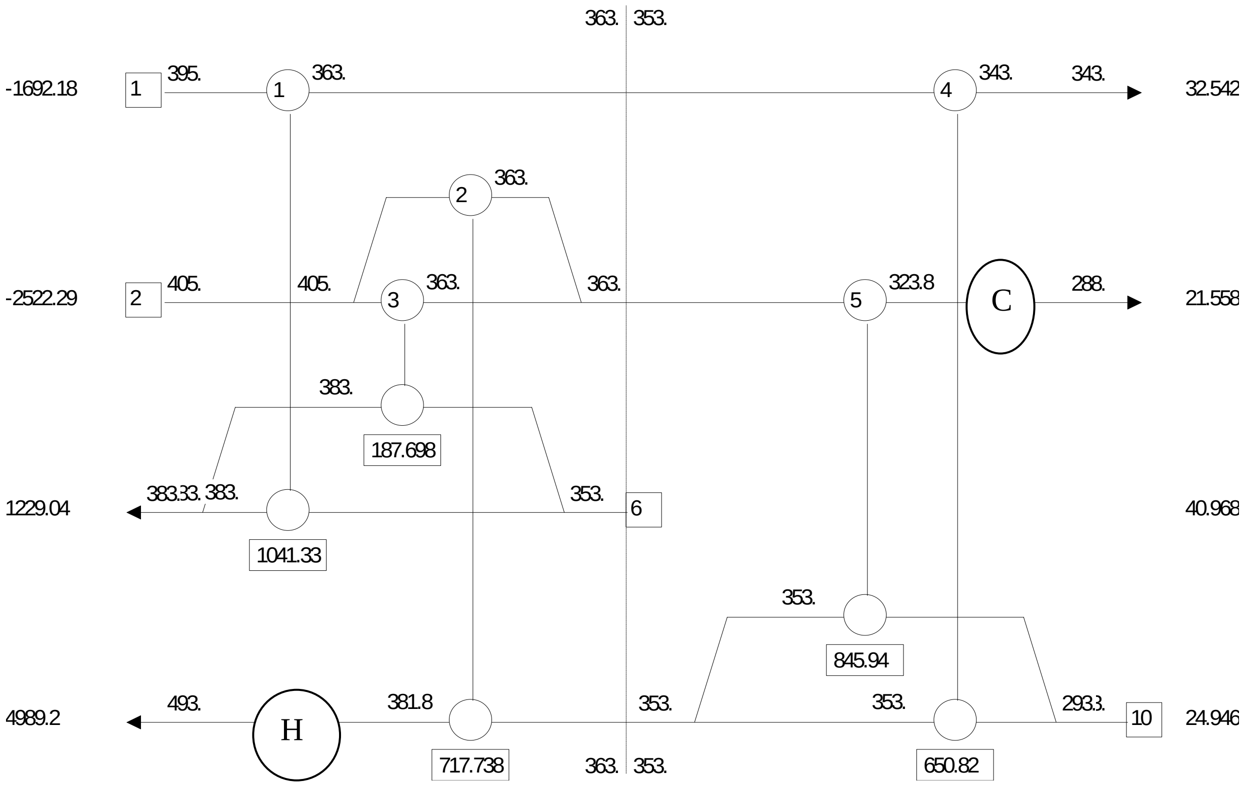

Fig 5.14 Design 2 of Problem 1 (Variable CP)

5.6.2 Problem 2

For constant CP two designs are proposed in fig 5.15 and 5.16. In the design 1 two heaters are required one of duty 0.5348 MW and other one of 2 MW and one cooler of duty 0.446 MW. The sum of both heater duties is equal to the required heating duty of 2.5348 MW and cooler duty is 0.0.446 MW. In the design 2 one heater and one cooler is required of duty 2.714 MW and 0.792 MW respectively. So for constant CP design 2 are proposed because capital cost is reduced and the designs are shown in fig. 5.16.

Also for variable CP two designs are proposed in fig 5.17 and 5.18. In the design 1 one heater of duty 2.006 MW and other of duty 0.5849 MW which gives total of 2.5909 MW and cooler duty is 0.4644 MW which is less than the required hot and cooling duty of 2.6524 and 0.4874 MW. In the design 2 one heater and one cooler is required of duty 2.6002 MW and 0.4644 MW respectively. So for variable CP design 2 is proposed because it is closer to required duty. So the proposed design is under designed by 9.76 % and the designs are shown in fig. 5.18.

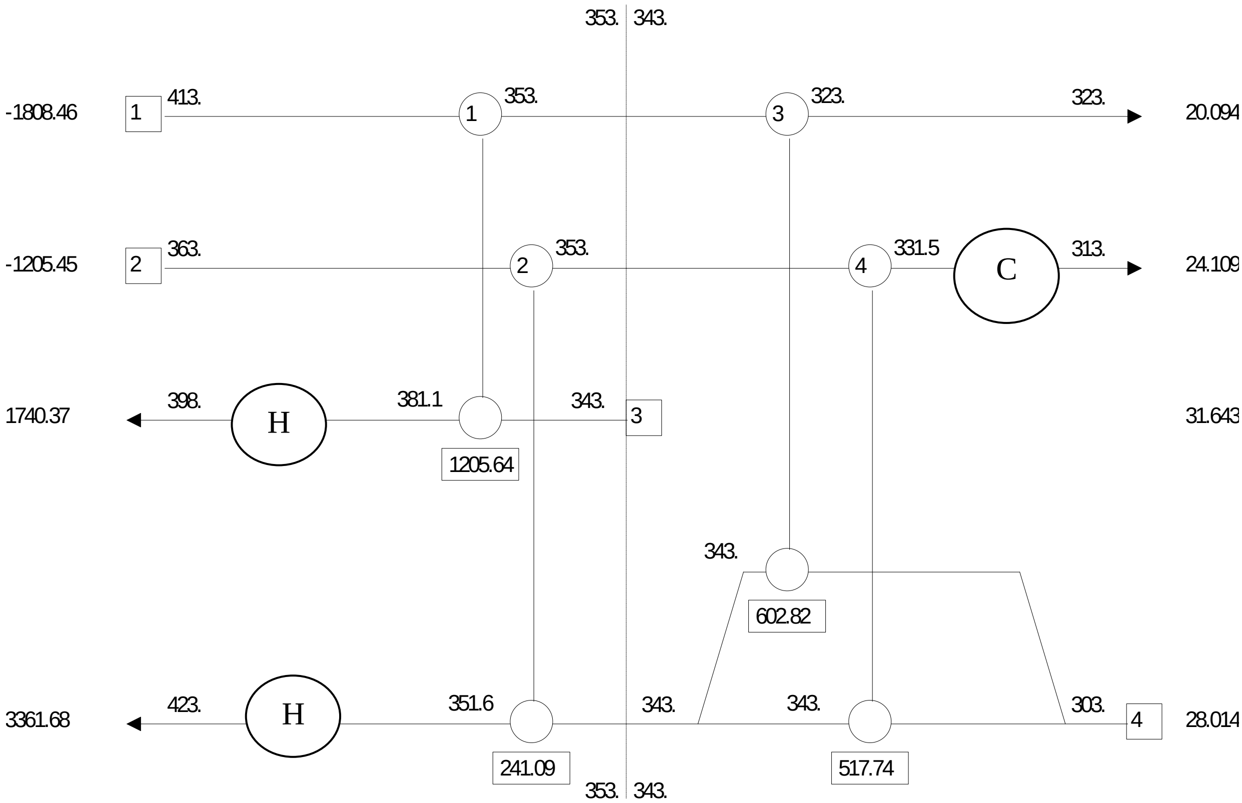

Fig 5.15 Design 1 of Problem 2 (Constant CP)

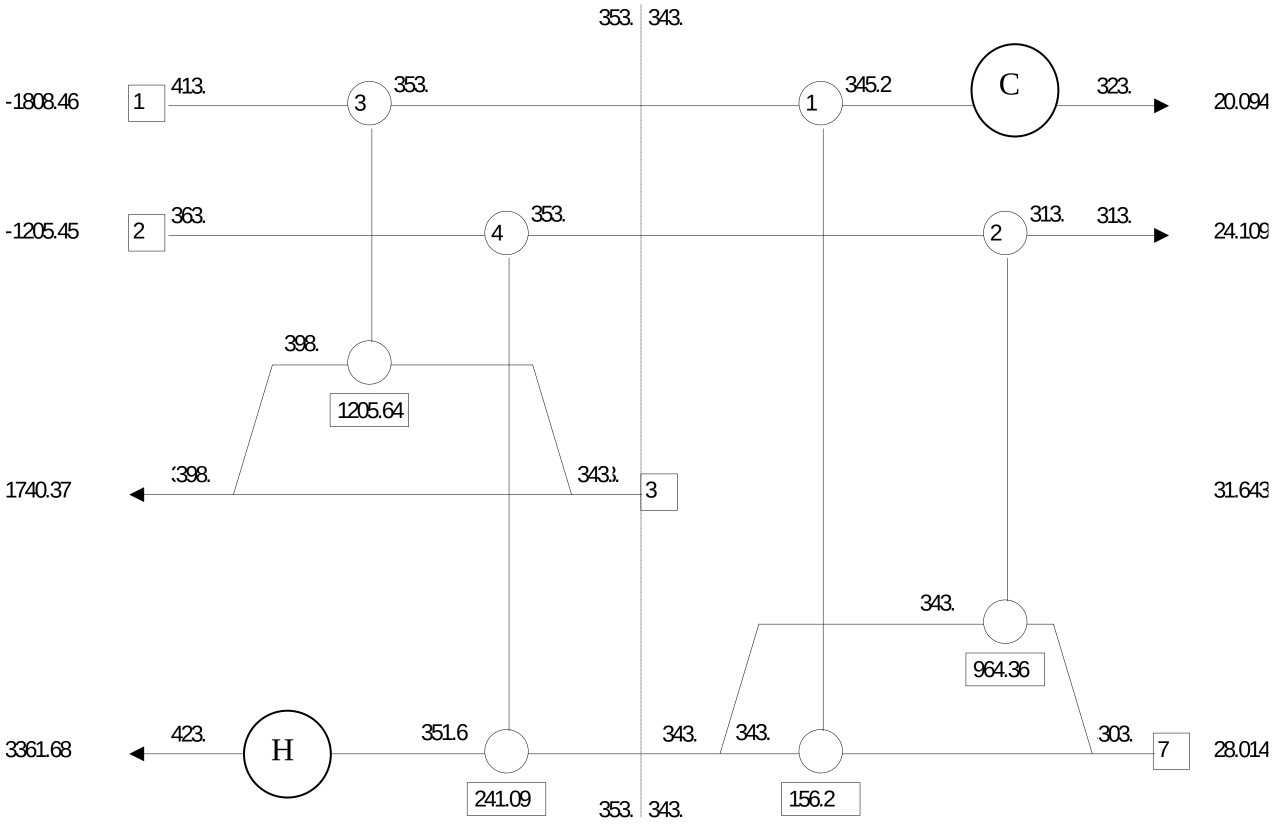

Fig 5.16 Design 2 of Problem 2 (Constant CP)

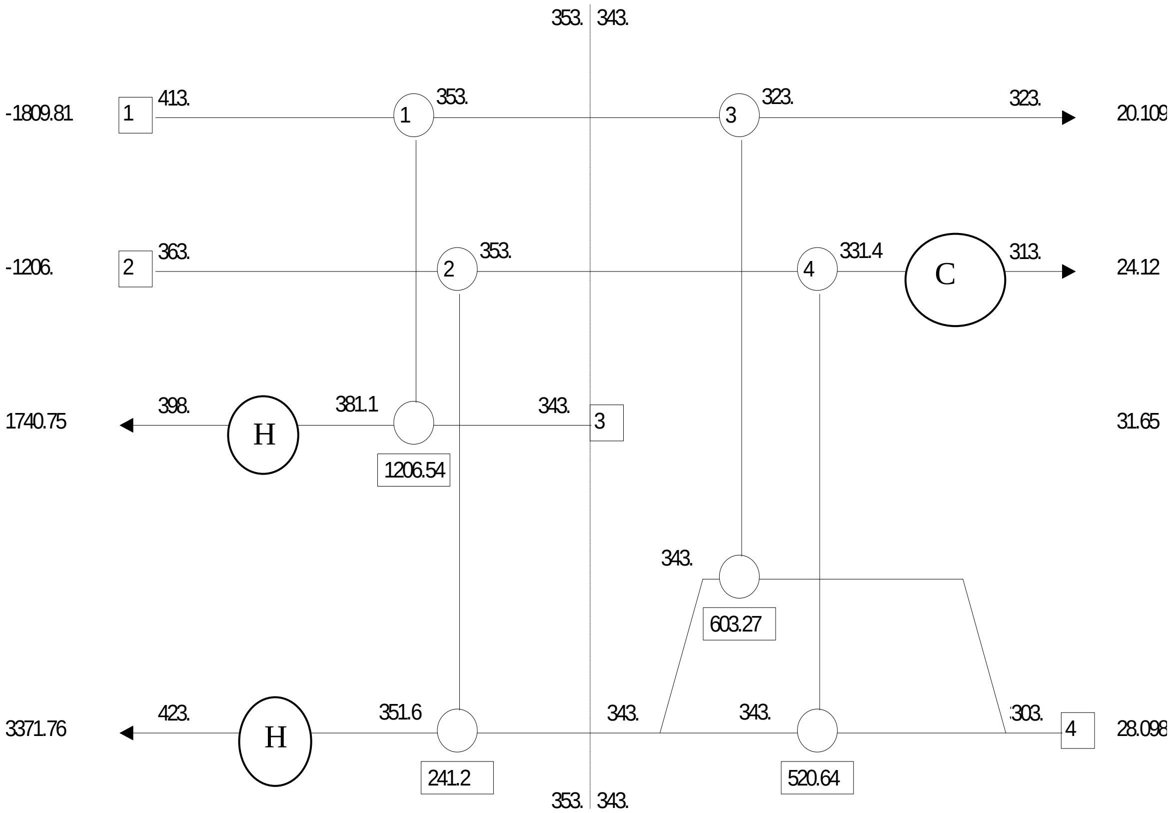

Fig 5.17 Design 1 of Problem 2 (Variable CP)

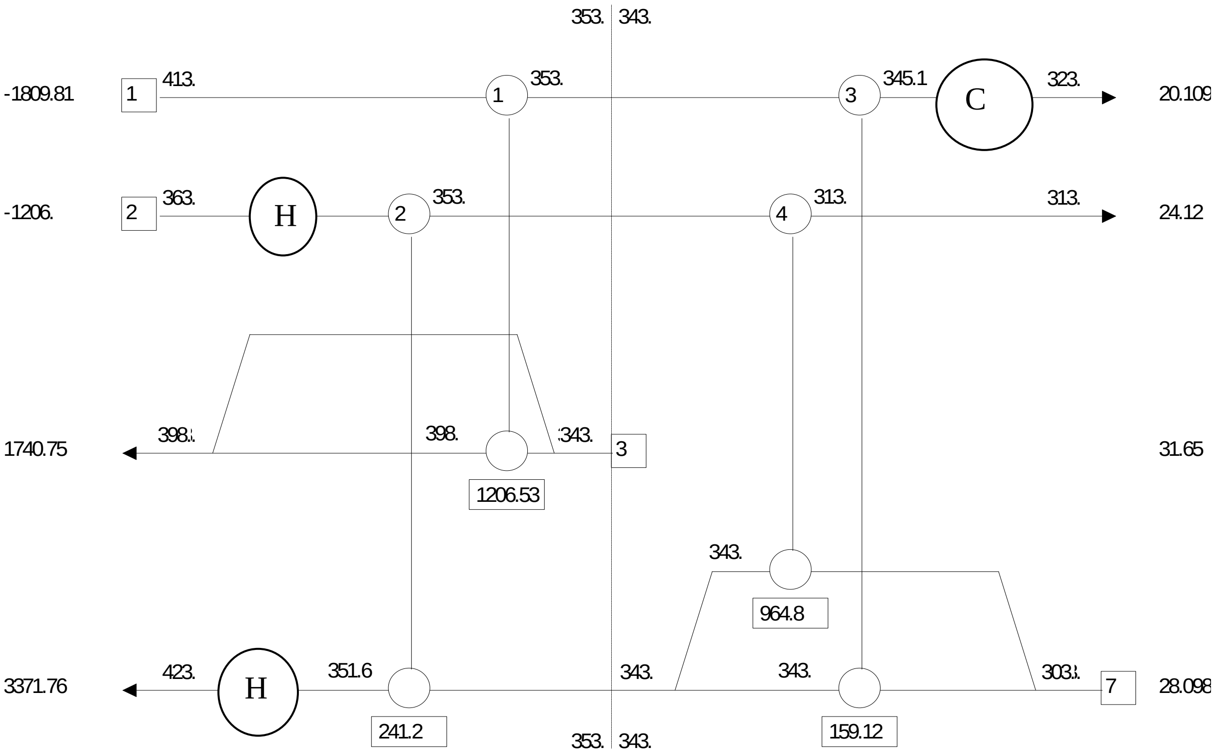

Fig 5.18 Design 2 of Problem 2 (Variable CP)

CHAPTER 6

CONCLUSIONS

The technology of energy integration is an outstanding approach for reducing the consumption of energy and increases the profit throughout the process. Due to continuous increase in the cost of energy and depletion of conventional resources of energy also day by day growing environmental problem there are strict need of to reduce the energy consumption by improving the existing process. In refineries except the cost of crude, energy took huge sum of money which can be modified if a better design being presented and has therefore become our focus.

Lots of technique has been presented for the study of heat exchanger network problems like tree searching, mixed integer non linear programming, genetic algorithm, graphical method. Pinch technology also called graphical method. In all these method this work is limited to pinch technology because it is the most notable method in all method due its easy technique and robustness.

Three problems have been taken and the temperature dependency of process streams has been seen when performed energy, area, no. of unit and super targeting. Also the design of HEN also presented by considering constant and variable CP of process streams. It has been observed that when consider variable CP utility increases by 10.14 % and 6.94 % respectively for problem 1. For problem 2 it increases by 4.64 % and 9.14 % respectively. But for problem 3 increase in hot utility by 6.83 % and decrement in cold utility by 19 %. Also design of heat exchanger network also presented here. So there is need to consider the temperature while designing heat exchanger network.

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APPENDIX-A

Table A-1 Data for Balance composite Curve for Problem-1 (constant CP)

Balance Composite Curve			
T_h	Q_{cum}	T_c	Q_{cum}
K	**MW**	**K**	**MW**
288	0	278	0
343	1.1857	288	0.7709
395	3.9989	293	0.7709
405	4.2145	353	2.2677
520	4.2145	383	4.2451
521	6.989	493	6.989

Table A-2 Data for Data for Balance composite Curve for Problem-1 (Variable CP)

Cold and Hot Composite Curve			
T_h	Q_{cum}	T_c	Q_{cum}
K	**MW**	**K**	**MW**
288	0	278	0
343	1.1412	289.6	0.9854
395	3.9845	293	0.9854
405	4.2144	353	2.2855
520	4.2144	383	4.2148
521	7.204	493	7.204

Table A-3 Data for Balance composite Curve for Problem-2 (constant CP)

Hot and Cold Composite Curve			
T_h	Q_{cum}	T_c	Q_{cum}
K	**MW**	**K**	**MW**
313	0	283	0

323	0.2412	293	0.4420
363	2.0092	303	0.4420
413	3.0142	343	1.5659
522	3.0142	398	4.8521
523	5.555	423	5.555

Table A-4 Data for Balance composite Curve for Problem-2 (Variable CP)

Hot and Cold Composite Curve			
T_h	**Q_{cum}**	**T_c**	**Q_{cum}**
K	**MW**	**K**	**MW**
313	0	283	0
323	0.2338	293	0.487
363	1.9858	303	0.487
413	3.0158	343	1.516
522	3.0158	398	4.823
523	5.66	423	5.66

Table A-5 Data for Area Targeting Problem –1 (Constant CP)

Interval	$\mathbf{Q_{cum}}$	$\mathbf{T_{hi}}$	$\mathbf{T_{ci}}$	**∑(CP/h)$_h$**	**∑(CP/h)$_c$**	**∑(Q/h)$_i$**	**(LMTD)$_i$**	$\mathbf{A_i}$
	MW	K	K	m^2	m^2	m^2-K	K	m^2
0	0.0000	288	278	0	0	0	0	0
1	0.7929	324.8	288	86.12	113.2757	4301.973	20.5693	209.1454
2	0.7929	324.8	293	86.12	0	0	34.23918	0
3	1.1842	343	308.95	86.12	136.1556	3739.066	32.91218	113.6073
4	2.2634	363.02	353	201.9521	136.1556	10040.74	19.64444	511.1235
5	3.9902	395	379.42	201.9521	321.8237	14961.01	12.59614	1187.745
6	4.2055	405	382.72	86.12	321.8237	1923.218	18.73071	102.6773
7	4.2055	520	382.72	0	321.8237	0	63.24473	0
8	4.2241	520	383	2857.263	321.8237	90.11064	137.14	0.657071
9	6.9199	521	493	2857.263	136.1556	17834.38	68.64946	259.789

Total Area = 2384.74 m^2

Table A-6 Data for Area Targeting Problem – 1 (Variable CP)

Interval	$\mathbf{Q_{cum}}$	$\mathbf{T_{hi}}$	$\mathbf{T_{ci}}$	**∑(CP/h)$_h$**	**∑(CP/h)$_c$**	**∑(Q/h)$_i$**	**(LMTD)$_i$**	$\mathbf{A_i}$
	MW	K	K	m^2	m^2	m^2-K	K	m^2
0	0.0000	288	278	0	0	0	0	0
1	0.9854	335.49	289.6	82.621	121.143	5328.93	23.55509	226.2326
2	0.9854	335.49	293	82.621	0	0	44.16819	0
3	1.1412	343	300.27	85.368	115.996	1484.405	42.60989	34.83709
4	2.2855	363.93	353	195.082	120.985	10462.61	23.32421	448.5727
5	3.9845	395	379.42	211.287	313.624	14850.63	13.11793	1132.087
6	4.2144	405	382.99	91.992	333.21	2109.48	18.61023	113.3505
7	4.2144	520	382.99	0	333.21	0	62.89112	0
8	4.2148	520	383	3146.947	335.858	3.35858	137.005	0.024514
9	7.2040	521	493	3146.947	150.949	19751.34	68.64946	287.7129

Total Area = 2242.82 m^2

Table A-7 Data for Area Targeting Problem –2 (Constant CP)

Interval	Q_{cum}	T_{hi}	T_{ci}	$\sum(CP/h)_h$	$\sum(CP/h)_c$	$\sum(Q/h)_i$	$(LMTD)_i$	A_i
	MW	K	K	m^2	m^2	m^2-K	K	m^2
0	0.0000	313	283	0	0	0	0	0
1	0.2411	323	288.4	160.7267	62.03056	1942.232	32.24533	60.23296
2	0.4466	327.65	293	241.1027	62.03056	1406.468	34.62499	40.62003
3	0.4466	327.65	303	241.1027	0	0	29.36678	0
4	1.5672	353	343	241.1027	133.4	11447.95	16.23823	705
5	2.0092	363	350.44	241.1027	250.5963	4275.463	11.23142	380.67
6	3.0139	413	367.27	80.376	250.5963	8236.336	25.66866	320.8713
7	3.0139	522	367.27	0	250.5963	0	89.4229	0
8	4.8483	522.72	398	2982.071	250.5963	9847.915	139.1862	70.75353
9	5.5487	523	423	2982.071	133.4	4169.98	111.9053	37.26347

Total Area = 1615.41 m^2

Table A-8 Data for Area Targeting Problem –2 (Variable CP)

Interval	Q_{cum}	T_{hi}	T_{ci}	$\sum(CP/h)_h$	$\sum(CP/h)_c$	$\sum(Q/h)_i$	$(LMTD)_i$	A_i
	MW	K	K	m^2	m^2	m^2-K	K	m^2
0	0.0000	313.00	283.00	0	0	0	0	0
1	0.2338	323.00	287.80	155.838	67.694	1883.478	32.52959	57.90045
2	0.5551	330.34	294.40	234.366	67.694	2166.368	35.56643	60.91046
3	0.5551	330.34	303.00	234.366	0	0	31.44212	0
4	1.5842	353.83	343.00	239.656	122.509	10531.18	17.83032	590.6334
5	1.9857	363.00	349.65	245.449	242.218	3859.631	12.04995	320.3027
6	3.0158	413.00	366.79	82.406	247.352	8359.856	26.46923	315.8329
7	3.0158	522.00	366.79	0	247.352	0	89.9702	0
8	4.8918	522.71	398.00	3120.471	258.182	10266.35	139.4051	73.64403
9	5.6680	523.00	423.00	3120.471	147.779	4607.652	111.8994	41.17672

Total Area = 1460.40 m^2

Table A-9 Data for BCC at different ΔT_{min} for Problem 1 at constant CP

ΔT_{min}	10	15	20	25	30	35	40	45	50
T_h	Cum Q_{hb} MW								
288	0	0	0	0	0	0	0	0	0
343	1.1842	1.1842	1.1842	1.1842	1.1842	1.1842	1.1842	1.1842	1.1842
395	3.9902	3.9902	3.9902	3.9902	3.9902	3.9902	3.9902	3.9902	3.9902
405	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055
520	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055	4.2055
521	**6.9199**	**7.1897**	**7.4595**	**7.7294**	**7.9992**	**8.2690**	**8.5388**	**8.7203**	**8.8428**
ΔT_{min}	10	15	20	25	30	35	40	45	50
T_c	Cum Q_{cb} MW								
278	0	0	0	0	0	0	0	0	0
288	0.7929	1.0628	1.3326	1.6024	1.8722	2.1420	2.4118	2.5933	2.7158
293	0.7929	1.0628	1.3326	1.6024	1.8722	2.1420	2.4118	2.5933	2.7158
353	2.2634	2.5332	2.8030	3.0729	3.3427	3.6125	3.8823	4.0638	4.1863
383	4.2241	4.4939	4.7637	5.0335	5.3033	5.5731	5.8430	6.0244	6.1469
493	**6.9199**	**7.1898**	**7.4596**	**7.7294**	**7.9992**	**8.2690**	**8.5388**	**8.7203**	**8.8428**

Table A-10 Data for BCC at different ΔT_{min} for Problem 2 at constant CP

ΔT_{min}	10	15	20	25	30	35	40	45	50
T_h	Cum Q_{hb} MW								
313	0	0	0	0	0	0	0	0	0

323	0.2411	0.2411	0.2411	0.2411	0.2411	0.2411	0.2411	0.2411	0.2411
363	2.0092	2.0092	2.0092	2.0092	2.0092	2.0092	2.0092	2.0092	2.0092
413	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139
522	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139	3.0139
523	**5.5487**	**5.7697**	**5.9907**	**6.1308**	**6.2708**	**6.4109**	**6.5510**	**6.6911**	**6.8311**
ΔT_{min}	10	15	20	25	30	35	40	45	50
T_c	Cum Q_{cb} MW								
283	0	0	0	0	0	0	0	0	0
293	0.4466	0.6676	0.8887	1.0287	1.1688	1.3089	1.4489	1.5890	1.7291
303	0.4466	0.6676	0.8887	1.0287	1.1688	1.3089	1.4489	1.5890	1.7291
343	1.5672	1.7882	2.0093	2.1493	2.2894	2.4295	2.5695	2.7096	2.8496
398	4.8483	5.0693	5.2904	5.4304	5.5705	5.7106	5.8506	5.9907	6.1308
423	**5.5486**	**5.7696**	**5.9907**	**6.1307**	**6.2708**	**6.4109**	**6.5510**	**6.6910**	**6.8311**

Table A-11 Data for BCC at different ΔT_{min} for Problem 1 at variable CP

ΔT_{min}	10	15	20	25	30	35	40	45	50
T_h	Cum Q_{hb} MW								
288	0	0	0	0	0	0	0	0	0
343	1.1412	1.1412	1.1412	1.1412	1.1412	1.1412	1.1412	1.1412	1.1412
395	3.9845	3.9845	3.9845	3.9845	3.9845	3.9845	3.9845	3.9845	3.9845
405	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144
520	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144	4.2144
521	**7.204**	**7.522**	**7.840**	**8.159**	**8.479**	**8.799**	**9.121**	**9.348**	**9.513**

ΔT_{min}	10	15		20		25		30	
T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}
K	MW	K	MW	K	MW	K	MW	K	MW
278	0	278	0	278	0	278	0	278	0
289.6	0.9854	289.9	1.3039	290.1	1.6215	290.2	1.9411	290.3	2.2605

293	0.9854	293	1.3039	293	1.6215	293	1.9411	293	2.2605
353	2.2855	353	2.6040	353	2.9216	353	3.2412	353	3.5606
383	4.2148	383	4.5333	383	4.8509	383	5.1705	383	5.4899
493	**7.204**	493	**7.522**	493	**7.840**	493	**8.159**	493	**8.479**

ΔT_{min}	35		40		45		50	
	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}
	K	MW	K	MW	K	MW	K	MW
	278	0	278	0	278	0	278	0
	290.4	2.5811	290.4	2.9028	290.6	3.1297	290.8	3.2951
	293	2.5811	293	2.9028	293	3.1297	293	3.2951
	353	3.8812	353	4.2029	353	4.4297	353	4.5951
	383	5.8105	383	6.1322	383	6.3590	383	6.5244
	493	**8.799**	493	**9.121**	493	**9.348**	493	**9.513**

Table A-12 Data for BCC at different ΔT_{min} for Problem 2 at variable CP

ΔT_{min}	10	15	20	25	30	35	40	45	50
T_h	Cum Q_{hb} MW								
313	0	0	0	0	0	0	0	0	0
323	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338	0.2338
363	1.9857	1.9857	1.9857	1.9857	1.9857	1.9857	1.9857	1.9857	1.9857
413	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158
522	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158	3.0158
523	**5.668**	**5.912**	**6.156**	**6.315**	**6.474**	**6.633**	**6.793**	**6.952**	**7.111**

ΔT_{min}	10	15		20		25		30	
T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}

K	MW	K	MW	K	MW	K	MW	K	MW
283	0	283	0	283	0	283	0	283	0
294.4	0.5551	294.5	0.7995	294.5	1.0435	294.7	1.2024	294.8	1.3614
303	0.5551	303	0.7995	303	1.0435	303	1.2024	303	1.3614
343	1.5842	343	1.8285	343	2.0726	343	2.2315	343	2.3905
398	4.8918	398	5.1361	398	5.3802	398	5.5390	398	5.6981
423	**5.668**	423	**5.912**	423	**6.156**	423	**6.315**	423	**6.474**

ΔT_{min}	35		40		45		50	
	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}	T_c	Q_{cb}
	K	MW	K	MW	K	MW	K	MW
	283	0	283	0	283	0	283	0
	294.9	1.5206	295.0	1.6804	295.0	1.8395	295.1	1.9985
	303	1.5206	303	1.6804	303	1.8395	303	1.9985
	343	2.5497	343	2.7095	343	2.8685	343	3.0276
	398	5.8573	398	6.0171	398	6.1761	398	6.3352
	423	**6.633**	423	**6.793**	423	**6.952**	423	**7.111**