Heat Exchanger Networks

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by

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CERTIFICATION

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Abstract

This study deals with the recovery of the energy available in hot and cold streams that exchanging heat. This can be done by heat exchanger network, to minimize the cost and the use of utilities. The transfer of energy from the hot stream to the cold stream depends on the rate of flow, area of the exchanger, the heat transfer coefficient and temperature gradient along each stream.

Heat exchanger networks were considered for three systems A, B and C. System A with four streams and systems B and C with six streams, all systems are in liquid phase only.

Heuristics, TI and pinch methods for heat exchanger networks were considered. Three heuristics which are Rudd, Kobayashi and Linnhoff were used, these heuristics are applied on system A first, which gives four possibilities when Rudd heuristic was used, the minimum configuration cost is the 2nd possibility which have a cost 36.2×10^6 ID/y. Eight possibilities where obtained when Kobayashi heuristic was used, the configuration which have a minimum cost is of 4th possibility where the cost was 36.2×10^6 ID/y, while Linnhoff heuristic gives one structure with cost $=113\times10^6$ ID/y. For system A, Rudd heuristic is the best, it gives the minimum cost structure in shortest way.

For system B, Rudd heuristic gives 5 possibilities, the minimum cost is for the 3rd possibility which is 107×10^6 ID/y. Kobayashi gives 25 possibility, the minimum possibility cost is the 1st which is 58.1×10^6 ID/y. Linnhoff possibility cost was 60.8×10^6 ID/y and it is close to the minimum cost structure. These heuristics were applied on system C but it gives unreasonable results.

TI method was considered on system A and C; a single structure was obtained for each system. For System A the cost was 47.5×10^6 ID/y and for system C cost was $565*10^6$ ID/y. Pinch method is applied on systems A and C and it gives the same possibilities and same costs as for TI method.

The minimum approach temperature was selected to be 11 ^oC (20 ^oF) for all above cases, because it is the most appropriate value for the shell and tube heat exchangers when the minimum approach temperature reduced to 5.5 ^oC (10 ^oF) for solving system C, the cost obtained by this value for the single structure of this system is equal to $1{,}015\times10^6$ ID/y and 565×10^6 ID/y if ΔT_{min}=11 ^oC.

The results obtained from this work was compared with the results of the previous works for the same systems, a difference about 46% in the value of the cost will be notice, as in the cost for the 2nd possibility in system A (Kobayashi heuristic) which is 60.9×10^6 ID/YR in 1975 and 792×10^6 ID/YR in the present years after correcting the costs for the utilities (steam and cooling water) by the cost index to the last year and because of the change of the cost of materials for the heat exchangers.

CONTENTS

Nomenclature

Symbol	Definition	Dimensions
A_E	area of heat exchangers	m^2
A_H	area of heaters	m^2
A_C	area of cooler	m^2
a, b	cost parameters	—
C_E	cost of heat exchangers	ID/y
C_H	cost of heaters	ID/y
C_C	cost of coolers	ID/y
C_S	cost of steam	ID/y
C_W	cost of cooler	ID/y
C_p	heat capacity	kJ/kg. ^oC
C_{pw}	heat capacity of cooling water	kJ/kg. ^oC
F_t	correction factor for heat balance eq.	—
H	Enthalpy	kJ/kg
i ,j	number of streams	—
M	total number of hot streams	—
m	mass rate	kg/s
m_s	mass rate of steam	kg/s
m_w	mass rate of cooling water	kg/s

N	total number of cold streams	–
N_s	number of streams	–
N_u	number of utilities	–
N_I	number of independent variables	–
N_H	number of heat exchangers	–
P_S	saturated pressure of steam	–
Q	heat load	kJ/hr
S_{hi}, S_{hj}	number of hot streams	–
S_{ci}, S_{cj}	number of cold streams	–
T	Temperature	^oC
U	Heat Transfer Coefficient	$kJ/m^2.hr.\,^oC$
W	capacity flow rate	$kJ/s.\,^oC$

Greek	**Definition**	
Δ	difference in quantity	
δ	annual rate of return	
λ	latent heat of evaporation	kJ/mole

Subscript

hi, hj	number of hot streams

ci ,cj	number of cold streams
i	number of intervals
lm	logarithmic mean
min	minimum
E	exchanger
H	heater
C	cooler
W	cooling water
S	steam
U_t	utilities

Chapter One
INTRODUCTION

1.1. Introduction:-

While oil prices continue to climb, energy conservation remains the prime concern for many process industries. The challenge every process engineer is faced with, is to seek answers to questions related to their process energy patterns [1].

Energy conservation is important in any chemical plant or process for a profitable operation. It can be done by using heat transfer equipment, where it is very vital in any process industry, especially the heat exchangers and their optimal design is of crucial importance in terms of performance and economy[2].

Before the petroleum crises in the 1970, energy costs usually represented around 5% of the total plant cost. Subsequently, the energy cost component rose to around 20%, causing the industry to rethink its approach to process design in more parsimonious terms. Since then, the problem of the design of heat exchanger networks – on the main process synthesis problems – Has been receiving a great deal of attention [3].

The supply and removal of heat in a modern chemical process plant represents an important problem in the process design of the plant. The cost of facilities to accomplish the desired heat exchange between the hot and cold media may amount to one third of the total cost of the plant. Thus, a lot of research work has been done to find the minimum cost configuration of a Heat Exchanger Network (HEN) both in terms of total cost and operability. One of the most important insights that have been developed to overcome the combinatorial nature of this problem is the predication of the minimum utility target, which can be performed to develop the network structure [4].

Process streams at high pressure or temperature, and those containing combustible material, contain energy that can be usefully recovered. Whether it is economic to recover the energy content of a particular stream will depend on the value of the energy that can be usefully extracted and the cost of the recovery. The value of the energy will depend on the primary cost of the energy at the site. It may be worth while recovering energy from a process stream at a site where energy costs are high but not where the primary energy costs are low. The cost of recovery will be the capital and operating cost of any additional equipment required. If the savings exceed the operating cost, including capital charges, then the energy recovery will usually be worth while [5].

In industry there is a still of potential to make an energy system more efficient and thereby reduce the waste heat available. On the other hand there is an option to export the waste heat to another industry or to society. When the use of a heat exchanger network is considered for these tasks, the optimization framework developed in this work can be implemented to calculate the cost of optimal investments [6].

The most common energy recovery technique is to utilize the heat in a high temperature process stream to heat a colder stream: saving steam costs and also cooling water, if the hot stream requires cooling. Conventional shell and tube exchangers are normally used. More total heat transfer area will be needed, over that for steam heating and water cooling, as the overall driving forces will be smaller [7].

The HEN synthesis task consists of finding a feasible sequence of exchangers in which pairs of streams are matched, such that the network have a minimum cost as judged from overall large of possible stream combinations. Even for small problems all possible networks cannot normally enumerated [8].

The cost of a recovery will be reduced if the streams are located conventionally close. The amount of energy that can be recovered will depend on the temperature, flow rates, heat capacity, and temperature change possible, in each stream. A reasonable temperature driving force must be maintained to keep the exchanger area to a practical size. The most efficient exchanger will be the one in which the shell and tube flows are truly counter current. Multiple tube pass exchangers are usually used for practical reasons. With multiple tube passes the flow will be part counter current and part co –current and temperature a crosses can occur, which will reduce the efficiency of heat recovery [9].

1.2. Aim of This Work:-

This work presents a framework for generating flexible heat exchanger networks over specified range of variations in the flow rates and temperatures of the streams. So that the total annual cost (TAC) as result of utility charges, exchanger areas and selection of matches are minimized.

The aim of this work is to create a minimum investment cost with practically fixed and a minimum operating cost for the heat exchanger network, while achieving a maximum amount of heat exchange among hot and cold process streams. Three systems were considered and three different methods were applied, which are the heuristics method, temperature interval and pinch analysis method to give the best method which gives the minimum cost structure according to the area, cost and minimum number of heat exchangers.

Chapter Two
LITERATURE SURVEY

2.1. Introduction

Heat exchanger network (HEN) synthesis was one of the most extensively studied problems in industrial process synthesis. This was attributed to the importance of the determining the energy costs for a process and improving the energy recovery in industrial sites [6].

It has got much attention during the last decades. All the early models assumed temperature independent heat capacity flow rates and heat transfer coefficients, and even today, most existing models are set under the same assumption. Removing this assumption, many standard rules are set aside and networks with heat exchange across pinch – points and even networks including external cooling of a heat source at its highest temperature may be found optimal [9].

Many problems in economy and engineering are not tractable by exact mathematical models due to complexity of the problem or uncertain and incomplete data based on which decisions have to be made. For such problems a large number of heuristics rules and strategies have been derived from experience and other sources [10].

2.2. Heat Exchangers:-

The transfer of heat to and from process fluids is an essential part of most chemical processes. The word "exchanger "really applies to all types of equipment in which heat is exchanged but is often used specifically to denote equipment in which heat is exchanged between two process streams.

In a heat exchanger, the device most commonly used for thermal energy task combination, two fluids pass on opposite sides of a conducting surface. As a consequence of the second law of thermodynamics, heat energy transfers through this surface from warmer fluid to colder [(6)].

The design engineer should consider both process design and mechanical design when preparing the specifications for a heat exchanger. The following list presents the basic information that should be supplied to a fabricator in order to obtain a cost estimate on a proposed heat exchanger [(7)].

The process Design Information is:

1. Fluids to be used including fluid properties if they are not readily available to the fabricator.
2. Flow rates or amounts of fluids.
3. Entrance and exit temperatures.
4. Amount of vaporization or condensation.
5. Operating pressures and allowable pressure drops.
6. Fouling factors.
7. Rate of heat transfer.

The Mechanical Information is:

1. Sizes of tubes. (Diameter, Length, Wall thickness)
2. Tube layout and pitch. (Horizontal tubes, Vertical tubes)
3. Maximum and minimum temperatures and pressures.
4. Necessary corrosion allowances.
5. Special codes involved.
6. Recommended materials of construction.

Some of preceding information can be presented in the form of suggestions with an indication of the reasons for the particular choice. This would apply, in particular, to such items as fouling factors, tube layout, codes, and materials of construction (11).

2.2.1. Equipment Types for Heat Exchange:

A wide Varity of equipment is available for conducting heat exchange. Commercial units range in size from very small , double pipe heat exchangers, with less than 9.29×10^{-2} m^2 (1 square foot) of heat transfer surface, to large air cooled units called fin-fan heat exchangers because they consist of tubes with external peripheral fins and fans to force air past the tube. It is usually the only type which can be considered for large surface areas having pressure greater than 30 bars and temperature greater than 260 ^oC. Finned areas in a single unit is as large as 1858 m^2 (20000 square feet). The most common unit is shell and tube heat exchanger, which comes in a variety of configurations in sizes from 4.645 to 1858 m^2 (50 to 20000 square feet). For specialized applications compact heat exchangers are challenging shell and tube units (12).

2.2.2. Equipment Selection for Heat Exchange in the Heat Exchanger Network.

The shell and tube heat exchanger is the most common of various types of unfired heat transfer equipment used in industry. Although it is not especially compact, it is robust and its shape makes it well suited to pressure operation. It is also versatile and it can be designed to almost any application.

A shell and tube heat exchanger consists of a shell, invariably cylindrical containing a nest of tubes plain or finned, which run parallel to the longitudinal axis of the shell, and are attached to perforated flat plates, baffles at each end. The tubes pass through a number of baffles, along their length which serve to support them and to direct the fluid flow in the shell. The assembly of tubes and baffles is a tube bundle held together by a system of tie rods and spacer tubes. The fluid which flows inside the tubes is directed by means of special ducts, known as stationary and near heads or channels [(12)].

One Fluid stream flows through the inside of several tubes in parallel on the tube side of heat exchanger, while the other fluid flows over the outside of the tubes on the shell side of the heat exchanger. Baffles are used on the shell side to make the fluid flow back and fourth across the tubes at the desired velocity [(13)].

The amount of heat exchanged depends on the flow rates, temperature difference, and thermal properties of the fluids, as well as the design of heat exchangers, in particular the heat exchange surface area.

In co-current operation the hot and cold streams pass through the exchanger in the same direction, and in counter current operation the streams flow in opposite directions. The direction of flow has a significant effect on the exchanger.

2.3. Heat Exchanger Networks:

Networks of heat exchangers are commonly used to recycle energy within a process, avoiding the escape of energy with effluent materials .If the process runs at high temperatures such as in the distillation of sea water, the hot effluents are used to heat the colder feed. On the other hand, if the process runs at low temperature, such as in desalination by freezing, the cold effluents are used to cool the warmer feed. The sequence of heat exchange operation is an aspect of task integration.

An important process design problem is the synthesis of minimum cost network of heat exchangers to transfer the excess energy for a set of hot streams to streams that require heating (cold streams).

In most analysis of heat exchanger networks, at any stage in process creation, it is common initially to disregard power demands in favor of designing an effective network of heat exchangers by heat integration, without using the energy of the high streams to produce power.

To accomplish this Ni hot process streams, with specified source and target temperatures $T_{hi}(s)$ and $T_{ho}(s)$, i=1,2,3,….,N_1,and cooled by cold process streams, with specified source and target temperature $T_{ci}(s)$ and $T_{co}(t)$, J=1,2,3,….,N_2, figure(2.1a). Because the sum of the heating requirements does not equal to the sum of the cooling requirements, and because some source temperatures may not be sufficiently high or low to achieve some target temperatures through heat exchanger, or when other restrictions exist, it is always necessary to provide one or more auxiliary heat exchangers for heating or cooling through the use of utilities such as steam and cooling water. It is common to refer to the heat exchangers between the hot and cold process streams as comprising the auxiliary network, figure (2.1 b).

When carrying out the design, given the states of the source and target streams, flow rates of the specie, temperature, pressure and phase, it is desired to synthesize the most economical network of heat exchanger [(12)].

The amount of energy that can be recovered will depend on the temperature, flow heat capacity, and temperature change possible in each stream.

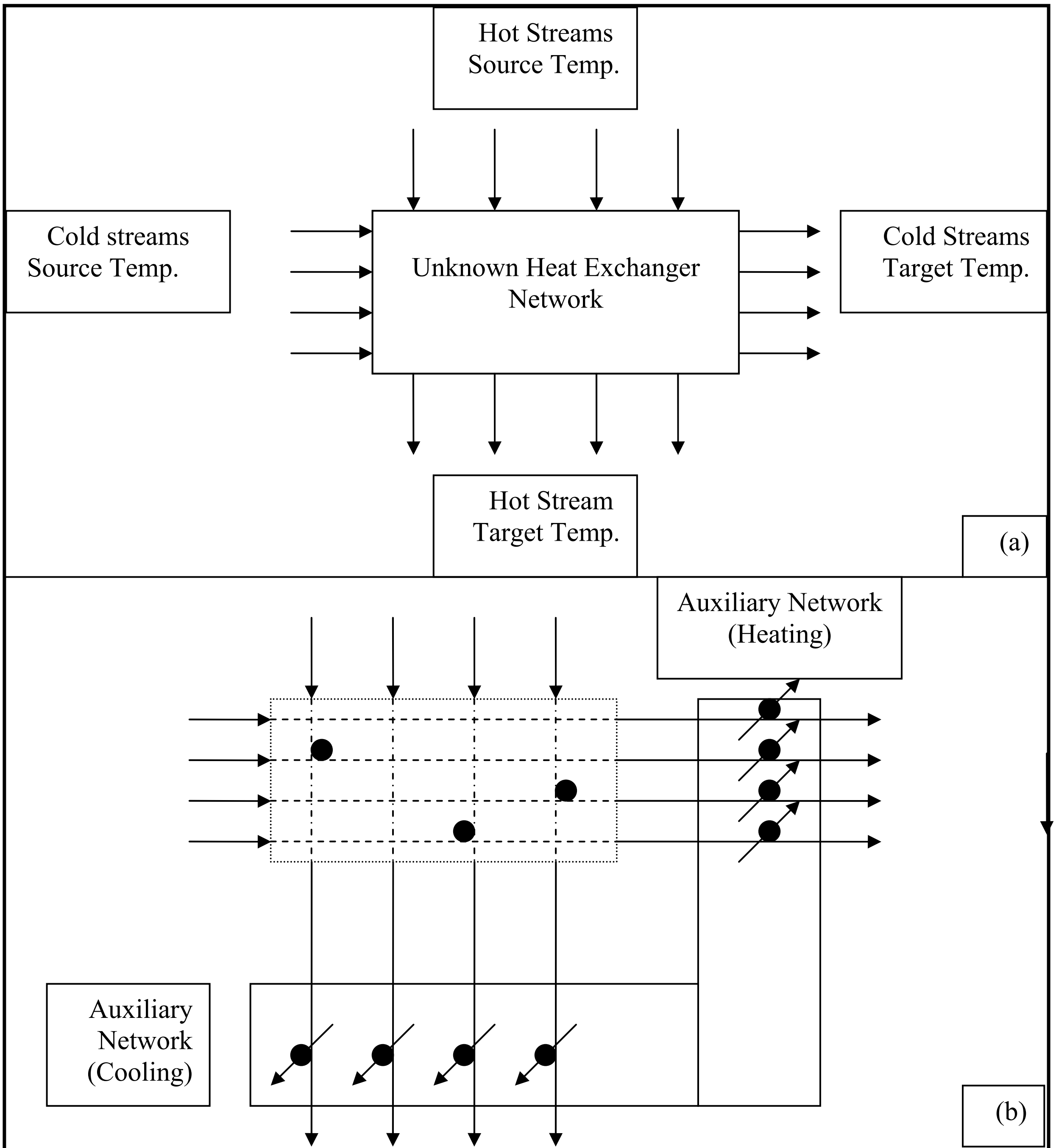


Figure (2.1): Heat Integration Schematics
a- Source and Target temperature for heat integration.
b- Interior and auxiliary networks of heat exchangers.

Shell and tube heat exchangers are normally used in HEN. Individual heat exchangers are more effective when internal flow of hot and cold fluids is counter current; this because the cold fluid temperature is driven toward the highest hot fluid temperature and the hot fluid temperature is driven toward the coldest cold fluid temperature. While in co-current, the hot and cold fluids are driven toward intermediate temperature [14].

The problem is to create a minimum cost network of exchangers that will also meet the design specifications on the required outlet temperature of each Stream. If the strictly mathematical approach is taken for setting up all possible arrangements and searching for the optimum, the problem even for small number of exchangers would require an inordinate amount of computer time [15].

With the design of the HEN, the objective is to recover heat from "hot" streams by matching with the "cold" streams .This matching process allows minimizing utilities (steam and cooling water) needed for heat duties [10].

2.3.1. Basic definitions.

To begin with the heat exchanger network synthesis approach, the basic definitions are:

a. Hot stream: Is a stream that needs to be cooled, $T_{out} < T_{in}$.

b. Cold stream: Is a stream that needs to be heated, $T_{out} > T_{in}$.

c. Stream flow rates: The flow rate of each stream must be given in the problem to compute the total heating and cooling duty.

d. Stream source temperature: It is the temperature at which the stream is available from the plant or process before it undergoes any heat exchange.

Typically, this is the battery limit temperature, or the temperature at which a stream originates from process equipment such as a reactor or distillation column.

e. Stream target temperature: It is the temperature at which the stream is desired, after all heat exchange has been completed, including heating by hot utilities such as steam, or cooling by cold utilities such as water. Typically, this is also a battery limit condition or the temperature at which a stream must enter appraises equipment such as an aerator or a distillation column.

f. Minimum approach temperature: It is the closest approach temperature that is allowable between two streams exchanging heat. There is no fixed number that can be uniformly recommended. The minimum approach temperature selected affects both the capital costs and the operating costs. Selecting low value means that hot streams can approach the temperature of the cold streams more closely. The cold stream thus absorbs more heat from the hot stream, this reduces the utility heating required for the cold stream and also the utility cooling required for the hot stream, as the hot stream exits as a lower temperature after heat exchange with the cold stream. This reduces the operating costs by lowering the utility costs, but it also increases the capital costs .Similarly, a large value of the minimum approach temperature results in lower capital costs and higher utility (operating) costs.

Therefore the area and hence the cost of exchanger is inversely proportional to the temperature differences. If the temperatures of the two streams are getting close together, a point is reached where it is more economical to perform the remainder of energy tasks with other integrations or external utilities rather than increase the size of the exchanger. The economic trade – off point occurs at minimum temperature difference of 8.3-11.11 ^{o}C (15 – 20 F^{o}) [16].

g. Utilities: The heating and cooling duties not serviced by heat recovery must be provided by external utilities including steam and cooling water. The cooling water is very suitable because of the abundance of water and of its high heat capacity. The use of recirculation water systems employed to reject waste heat to environment. It is used extensively as a heat exchange medium. The use of steam as a heat exchange medium is because the steam has a high latent heat of condensation per unit weight and therefore it is very effective as a heating medium [11, 17].

2.4. Heat Exchanger networking methods:

There are different methods for solving the problem of heat exchanger network, these methods are:

2.4.1. Heuristics Method:

The general techniques that have been developed previously for solving HEN problem included the heuristics approach based on the use of rules of thumb. The selection rules which favor the use of a given piece of equipment in certain phases of system synthesis evolve from experience and are thought to be part of the empirical skill of successful process designers. These rules may be wrong on occasion and will lead to non minimum cost systems, but the experienced designer requires only that the rules lead to efficient designs frequently enough to warrant their use. Heuristics rules are useful empirically but are unproved, or incapable of being proved [12].

The heuristics aims to optimize the objective function, the overall objective of the problem both the energy cost and the cost needed for the changes. Where the sequence of events is as follows: Suggestions is made up by the heuristics rules which gives a number of combinations for the system , after finding all the possibilities which can be obtained by this heuristic, followed by choosing the minimum cost network[18].

Heuristics are employed to reduce the computational effort. Termination of a stream at its desired temperature, when possible in an exchanger was found to speed the search without impairing the accuracy [(19)].

Many heuristics have been proposed by several workers [(10, 15, 16, 18, and 20)] to solve the problem of the heat exchangers network.

The first heuristic rules were given by lee et.al, branch and bound technique with tree searching were developed which helped to reduce the number of combinational possibilities to be enumerated [(18) (20)].

The heuristic developed by Kobayashi and Ichikawa [(15)] gives a lot of combinations, which matches each hot stream with each cold stream once in each structure.

Rudd et. al. [(16)] developed many heuristics that accomplish the required heat exchange with the lowest total cost including the investment cost in the heat exchanger, the auxiliary coolers, and heaters, and the purchase of steam and cooling water, the first heuristic is:

-Do not specify heat exchanger between two streams such that the temperature difference at either end is below the minimum –approach temperature.

Steam may only be available for heating at several temperatures. Similarly, cooling water, brine, glycol, propane, or other refrigerants will be available only at characteristic temperatures. Therefore, propose exchangers that will allow auxiliary heating to be done at the lowest possible temperature and auxiliary cooling at the highest possibilities temperature, so that auxiliary heating and cooling are done as close to ambient temperature as possible. This is especially important when alternative heat exchanger integration would require an auxiliary utility from a less expensive source. That led to two more useful heuristics:

A- Consistent with the minimum –approach temperature, propose heat exchange between the hottest stream to be cooled with the warmest stream to be heated.

Alternatively:

B- Consistent with the minimum approach temperature, propose the heat exchange between the coldest stream to be heated with the coldest stream to be cooled [16].

Ponton and Donaldson synthesis method was alternative to Rathore [20] method. It is mainly based on the heuristics of always matching the hot stream of highest supply temperature with the cold stream of highest supply temperature with the cold stream of highest target temperature.

Rathore and Powers [20] pointed out that costs for steam and cooling water will normally be more important than the cost for plant to the extent where several quite dissimilar network topologies will all feature near optimal costs in so far as they feature near maximum energy recovery.

For more complex cases, Linnhoff and Flower [10], proposed a systematic method required:-

a -Rank the hot and cold streams in deceasing order according to its heat capacity flow rates.

b -Specify matches between the first hot and first cold; second hot and second cold, etc., until the only original streams left is either all hot or all cold .

c -Match the largest remaining stream with the largest residual of the primary matches, the second largest remaining with the second largest residual, etc. at this stage, temperature constraints must be considered, whatever remains after these steps, that are original streams, primary residuals, secondary residuals. etc.

d -The final step is to match these against utility hot and cold.

This method will give a single design which may not be more convenient than other at a later stage in the synthesis but which will always produce a sub network structure in the heater and cooler loads are not greater than those obtained by different rules.

2.4.2. Temperature Interval Method (TI):

The temperature –interval method was developed by Linnhoff and Flower [10] following the pioneering work of Hohmann. Any network will solve the problem may be thought of as an array of sub networks. Each of these sub networks include all streams (or part of streams), which fall within a defined temperature interval. The temperatures T_1, T_2, T_3… T_{n+1} are deduced from the problem data in the following way: Each stream supply and target temperatures are listed after the temperatures of the hot streams have been reduced by the minimum temperature difference ΔT_{min}. The highest temperature in the list is called T_1, the second highest T_2, and so on. Generally, the following expression holds:-

$$N = 2Z - 1 \qquad \text{..... (2.1)}$$

Where N represents the number of sub networks can obtain for the system and Z: The number of streams.

Each sub network represents a separate synthesis task. However, since all streams in a sub network run through the same temperature interval, the synthesis task is very easy [10].

As will be seen, a systematic procedure unfolds for determining the minimum utility requirements over all possible HENs, given just the heating and cooling requirements for the process streams and the minimum approach temperature in the heat exchangers, ΔT_{min} [12].

It is a synthesis method used of the fact that desirable network structures will normally feature high degrees of energy recovery. The method deals with the problem in two stages, in the first stage, these preliminary networks are generated which exhibit the highest possible degree of energy recovery. In the second stage, these preliminary networks are used as convenient starting points when the searching for the most satisfactory network from other points of view part from costs criteria like safety constraints, controllability, etc. ,are easily observed .

The TI method allows the user to identify the upper bound on energy recovery for given heat exchanger network synthesis problem. This method is based on enthalpy balance, and to systematically generate a variety of networks, which perform at this upper bound. TI method produces the network with very small computational effort [(10)].

2.4.3. Pinch technology:

The term "Pinch Technology" was introduced by Linnhoff and Verdeveld [(21)] to represent a new set of thermodynamically based methods that guarantee minimum energy levels in design of heat exchanger networks. Over the last two decades it has emerged as an unconventional development in process design and energy conservation .The term pinch analysis is often used to represent the application of the tools and algorithms of pinch technology for studying industrial process.

Pinch technology presents a simple methodology for systematically analyzing chemical processes and the surrounding utility systems with the help of the first and second laws of thermodynamics. The first law of thermodynamics provides the energy equation for calculating the enthalpy changes (ΔH) in the streams passing through a heat exchanger .The second law determines the direction of heat flow .That is heat energy may only flow in the direction of hot to cold. This prohibits temperature crossovers of the hot and cold stream profiles through the exchanger unit. In a heat exchanger unit neither a hot stream can be cooled below cold stream supply temperature nor can a cold stream be heated to a temperature more than the supply temperature of a hot stream. In practice, the hot stream can only be cold to a temperature defined by the "temperature approach" of the heat exchanger. The temperature is the minimum allowable temperature difference (ΔT_{min}) in the stream temperature profiles for the heat exchanger unit. The temperature level at which (ΔT_{min}) is observed in the process is referred to as "pinch point" or "pinch condition". The pinch defines the minimum driving force allowed in the exchanger unit process. Integration using pinch technology offers a novel approach to generate targets for minimum energy consumption before heat recovery network design. Heat recovery and utility system constraints are then considered. The pinch design can reveal opportunities to modify the core process to improve heat integration. The pinch approach is unique because it treats all processes with multiple streams as a single, integrated system. This method helps to optimize the heat transfer equipment during the design of the equipment [(21) (22)].

Objectives of Pinch Analysis:

Pinch analysis is used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point .the procedure first predicts, a head of design, the minimum requirements of external energy, network area, and the number of units for a given at the pinch point. Next a heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy and the capital cost of the network so that the total annual cost is minimized. Thus, the prime objective of pinch analysis is to achieve financial savings by better process heat integration (maximizing process to process heat recovery and reducing the external utility loads) [1].

Most industrial processes involve transfer of heat either from one process to another process stream (interchanging) or from utility stream to a process stream. In the present energy studies all over the world, the target in any industrial process design is to maximize the process to process heat recovery and to minimize the utility (energy) requirements. To meet the goal of maximum energy recovery or minimum energy requirement an appropriate heat exchanger network is required. The design of such a network is not an easy task considering the fact that most processes involve a large number of process and utility streams. The traditional design approach has resulted in networks with high capital and utility costs. With the advent of pinch analysis concepts, the network design has become very systematic and methodical.

Summary of the key concepts, their significance and the nomenclature used in pinch analysis is given below:

a -Combined (hot and cold) composite curves: used to predict targets for minimum energy (both hot and cold utility), minimum network area, and minimum number of exchanger units.

b −ΔT_{min} and pinch point: the ΔT_{min} value determines how closely the hot and cold composite curves can be (pinched) or (squeezed) without violating the second law of thermodynamics (none of the heat exchangers can have temperature crossover). The pinch point is the temperature determined from the stream data and the approach temperature; it is used to separate the problem into two sub problems, called the problems above the pinch and below the pinch.

c −Grand composite curve: It is a plot of temperature on Y-axis versus the enthalpy flow on X-axis. If the curve touches the temperature axis at a value of 0.0 for the enthalpy, it is a pinched process, and the temperature corresponding to that point is the pinch temperature**.** Also, the grand composite can be used to determine the minimum amount of hot and cold utilities needed by the process [17].

d −Energy and Capital Cost Targeting: Used to calculate the total annual cost of utilities and the capital cost of heat exchanger network.

e −Total cost targeting: Used to determine the optimum level of heat recovery or the optimum ΔT_{min} value, by balancing energy and capital costs .Using this method, it is possible to obtain an accurate estimate within 10-15 percent of the overall heat recovery system. The assent of the pinch approach is the speed of economic evaluation.

Three rules for pinch method were summarized [1, 3, 17, 18, 22, 23, 24, 25, and 26]

1 - No external cooling above the pinch.

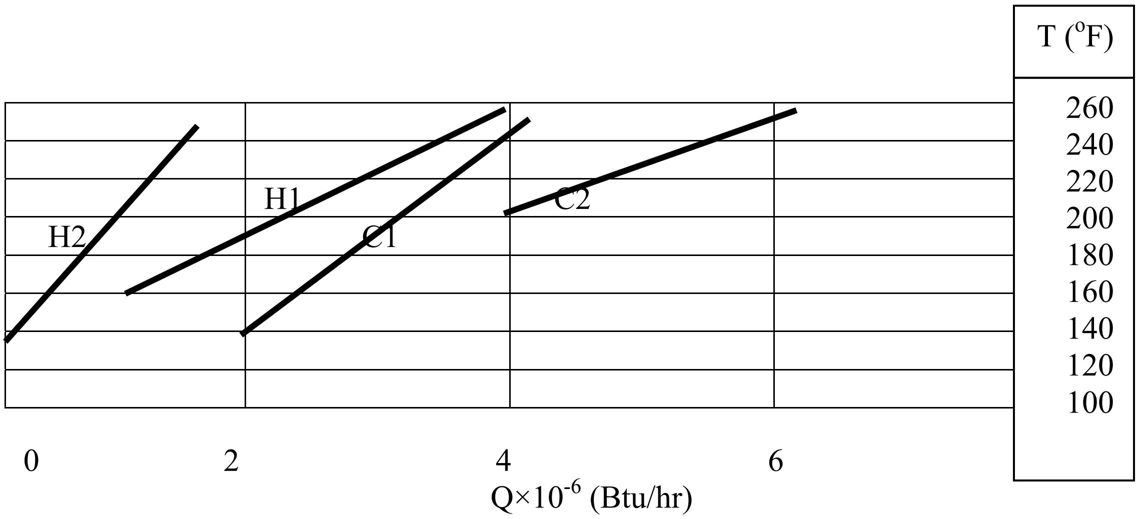
2 - No external heating below the pinch.

3 - No heat transfer across the pinch.

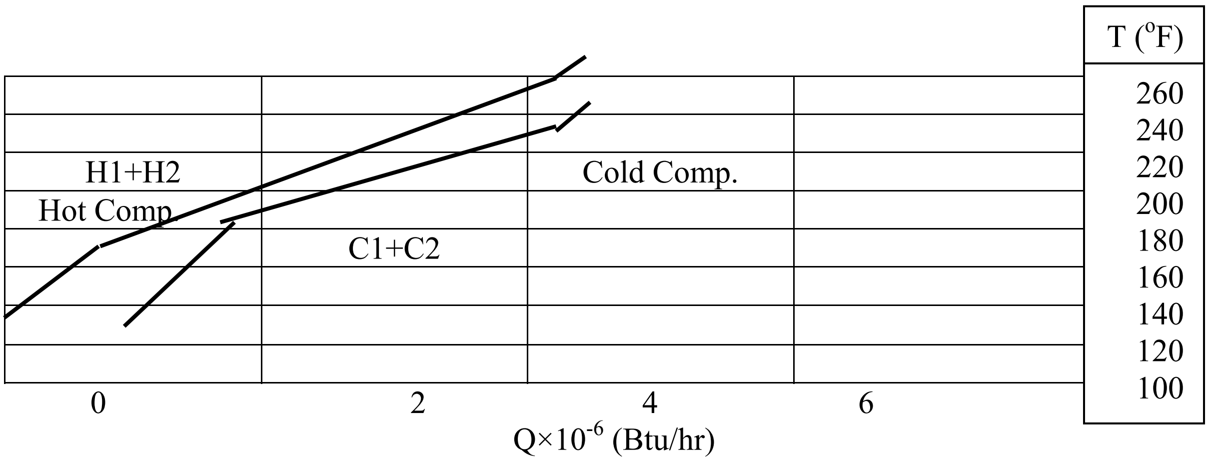
2.4.5. Graphical Displays:

The terminology "pinch" is understood more clearly in connection with a graphical display introduced by Umeda et al. (1978), in which composite heating and cooling curves are positioned no closer than ΔT_{min}. As $\Delta T_{min} \rightarrow 0$, the curves pinch together and the area for heat exchange approaches infinity.

To display the results of TI method graphically, we must find the data needed to prepare the hot and cold composite curves by finding the enthalpy for each temperature. First the hot composite curve is graphed starting with an enthalpy datum of 0 at the lowest temperature for the hot stream. Then we find the enthalpies for the hot composite to form the hot composite curve as in figure (2.2b).



(a)



(b)

Figure (2.3) Graphical method to locate the minimum utilities
a. heating and cooling curves for the streams.
b. composite hot and cold curves[12].

Next, the cold composite curve is graphed in the same way. For the specified ΔT_{min}, the TI method produces minimum cooling utilities, therefore, the graph begins with an enthalpy datum of that value, and then the cold composite enthalpies are found to form the cold composite curve as in figure (2.2b) [12].

2.4.6. Linear Programming Method:

A closer examination of the temperature –interval method shows that the minimum hot and cold utilities can be calculated by creating and solving a linear program (LP). Where, it is desired to determine the minimum hot and hot and cold utilities for a HEN by creating and solving in a linear programming using the energy balance for each interval in the cascade [12].

2.6. Review of Previous Work

The development of a theoretical approach to system synthesis is drawing increasing attention in various fields of engineering including process engineering.

Process system synthesis involves determining the optimal interconnection of processing units as well as the optimal type and design of the processing units within a process system.

An important process design problems in the synthesis of minimum cost network of heat exchangers to transfer the excess energy from a set of hot streams to streams that require heating (cold streams).

The problem can be stated thus: -given (n) streams to be heated and (m) streams to be cooled to find the heat exchanger networks which will carry out the desired temperature changes with the minimum cost .The cost is made up of two factors: -

1- The cost of heat exchangers to carry out the energy transfer and

2- The cost of utilities.

The minimum cost solution to this problem usually involves an integration of the hot and cold streams in heat exchangers to reduce the need for outside energy sources and sinks (utilities).

The networking of the heat exchanger networks has been studied by several workers, these workers names and their works listed in table below:-

Author	**Study**
Nishida *et. al.* (15)	Basic theorem derived on the basis of several assumptions to synthesize the optimal heat exchange system by sequential approach which has involved the synthesis of the system uses the basic theorem and computational algorithm of the complex method.
Kesler and Parker(27)	Formulated the energy integration as a linear programming and an assignment algorithm, which maintains the feasibility of the linear programming solution.
Rudd *et. al* .(16)	Used heuristics to determine the proper energy matches which would lead to efficient heat exchanger networks.
Lee *et al* (18)	Solved the problem of optimal heat exchanger networks by branch and bound technique.
Kobayashi *et.al.* (28)	proposed a systematic way of synthesizing an optimal heat exchange system by formulating the problem as an optimal assignment problem in linear programming, and of carrying out the optimal design of the synthesized system by the complex

	method of a computational algorithm, where, it plays an essential approach, both to eliminate some of the assumptions and to give practically meaningful results.
Pho and Lapidus [29]	Proposed a compact matrix representation of a cyclic exchanger network by tree search technique.
Ponton ,Donaldson	An alternative synthesis method based on the heuristics of always matching the hot stream of highest supply temperature with the cold stream of highest target temperature.
Rathore and Powers [20]	Pointed out that costs for steam and cooling water will normally be more important than the costs for plant to the extent where several, quite dissimilar network topologies will all feature near optimal costs in so far as they feature near maximum energy recovery.
Wright and Bacon [30] Nishida and Lapiduse [31]	Presented a statistical time series analysis methods in a paper. The objective is to demonstrate the application of these procedures to the modeling of a heat exchanger network. Gave the approach synthesis of minimum cost network of exchangers. The necessary conditions derived suggest a simple and practical algorithm called the minimum area algorithm for the synthesis of a minimum area and nearly minimum cost network of exchangers, heaters and coolers. The next step is to employ a set of simple evolutionary rules to systematically modify the resulting minimum area network so that the total cost of investments and utilities can be reduced.

Kelahan and Gaddy [19]	Presented a mixed integer optimization to solve the synthesis of heat exchange networks. Using the adaptive random search procedure, this can be used to search continuous and discrete independent variables simultaneously.
Linnhoff and Flower [10]	Introduced a systematic generation of energy optimal networks, where it is a thermodynamically oriented method for the heat exchanger network. With this method, the problem is solved in two stages, preliminary networks are generated which give maximum heat recovery, in the second stage, the most satisfactory final works are evolved using the preliminary networks as starting points.
Colbert [32]	Presented an industrial heat exchange network about a double temperature approach to synthesizing heat exchange systems, which provides the engineer with the strategy for balancing network complexity and costs. The DTA method requires the selection of two approach temperatures.
Annika Carlson [33]	Developed a user driven method for optimal retrofitting of heat exchanger network, with which all aspects relevant in a retrofit design situation can be taken into account.
Brend *et al.* [34]	Its study a bout optimization of heat exchanger networks by describing the adaptation of evaluation strategies (ES) s for simulation based HEN synthesis.
Samarjit and Ghosh [4]	Presents a new approach of HEN design making extensive use of randomization techniques. It is exceedingly simple to implement and gives new insight into the hardness and the cost space land

	underlying a given problem. At the same time, the results from their algorithm may be used as good initial solutions required by most non linear optimization problems.
Vieria *et al.* (35)	Based on fluid dynamical considerations on HENs, where it explores a new design algorithm about the total annual cost (TAC) optimization for a thermal equipment studying the tube side and shell side flow velocities constraints and also the influence of pumping cost in the networks final cost.
Abbass *et al.* (3) (36)	Based on constraint logic programming for chemical process synthesis. This method is novel in that it uses combinations of mathematical optimization techniques with backtracking heuristic search to achieve its results.
Jules Ricardo (37)	Presented a study for the pinch technology, it has been claimed that pinch technology is a tool that can be used for process design, however, based on the results of a challenge problem solved in the early 1990 s, it would appear that exergy analysis applied by an expert may be superior for that purpose.
Babu and Mohhidin (7)	Automated Design of Heat Exchangers by using an artificial intelligence based optimization, Genetic algorithm is applied to the optimal design of a shell and tube heat exchanger, and it is found to converge in very few (10) generations considering 6 as design variables with a total of 4608 configurations.
Nick Hallale (25)	Based on Burning Bright Trends in Process Integration, where, the process integration is more than just pinch technology and HENs on industries are making more money from their raw materials

	and capital assets while becoming cleaner and more sustainable.
Telang *et al.* (17)(23)	Introduced a user manual and tutorial of HEN, where it integrates the networks of heat exchangers, boilers, condensers and furnaces for best utilization by using the pinch analysis for the optimum of heat exchanger network .
Rakesh and Mehta (39)	Introduced a crude unit integrated energy analysis with the use of pinch analysis. This method produced a large increase in crude distillation capacity.
Hopper *et al.* (24)	Presented an advanced process synthesis system that has been developed to perform comprehensive evaluations on chemical plants and refineries for process improvements.
Juha Aaltola (40)	Presented a framework for generating flexible heat exchangers networks over a specified range of variations in the flow rates and temperatures of the streams.
Colin Howat (41)	Considered synthesizing as much heat as technically feasible using a cyclic network before using utilities for heating and/or cooling.
Yeap *et al.* (42)	Pointed out that the use of fouling factors in heat exchanger design and the lack of appreciation of fouling in traditional pinch approach has been resulted badly designed crude preheat networks that are expensive to maintain.
Anita and Glavic (43)	Proposed an optimization by stage –wise model for complex industrial heat exchanger network.

Chapter Three
THEORETICAL ASPECT

3.1. Introduction

The synthesis of Heat Exchanger Network Strategy adopted is to create a network of a minimum investment cost with a practically fixed and minimum utility operating cost, while achieving a maximum amount of hot and cold process streams.

In this work, Heat Exchanger Networks is considered using single phase streams. Heat balance equation was used to give the heat duty, and the missing variables which are the temperatures of the network, area of heat exchangers, and the cost for each exchanger and for the whole network. All the calculations were carried out using a developed computer program written in EXCEL language.

The capital cost of a network depends on a number of factors including the number of heat exchangers, heat transfer areas, materials of construction, piping, and the cost of supporting foundations and structures.

3.2. Methods of Analysis:-

The analysis emphasizes on studying and comparing different methods to analyze the heat exchanger networks and to find the best method of analysis to gives a rapid solution with minimum heat exchangers, coolers and /or heaters, and minimum utilities required with less cost.

The networking was carried out on three systems with four and six streams using three methods, heuristics method which involves three heuristics {Rudd (16), Kobayashi (28), and Linnhoff (10)}, temperature interval method [10], and pinch analysis method [22]. All the calculations are based on energy balance equation.

The source and target temperature, flow rate and heat capacity for each stream are available. The overall heat transfer coefficient and the cost of the utilities must be known to find the total cost for the network...

3.3. Specifications of Variables

The variables considered for the process systems are:

1. The flow rate for each stream.
2. Heat capacity for each stream.
3. The Input Temperature (T_i).
4. The output temperature (T_o).
5. Overall heat transfer coefficient (U).
6. Number of Hot Streams.
7. Number of cold streams.
8. Input temperature of cooling water.
9. Maximum output temperature of cooling water.
10. The saturated pressure of steam.

The systems used are given in tables (3.1, 3.2, and 3.3). These systems have been chosen because their data are available in literature [15, 16, 18, 19, 20, 22, 30, 31, 32, 33 and 34] and to compare the results obtained by the present work with previous works on the similar systems.

The results obtained for systems A, B and C are give in appendix B.

Where, system A and C were chosen to be solved by all the three methods in order to compare them according to the structures obtained. System C was solved by the TI method and pinch analysis method. While, system A was solved by all the three methods. And system B was chosen to be solved by just the heuristics method.

The Properties of the Three Systems

Table 3.1 {system A- Liquid} [15, 16, 18, 20, 28, 29]

Stream no.	Cap. Flow rate (J/s. °C)	T_{in} (°C)	T_{out} (°C)
1	7.621	60.0	160.0
2	6.081	116	260.0
3	8.792	160.0	93.3
4	10.548	249	138

Table (3.2) {system B- Liquid} [15, 16, 18, 20, 28, 29]

Stream no.	Cap. Flow rate (J/s. °C)	T_{in} (°C)	T_{out} (°C)
1	8438	37	221
2	17278	83	177
3	13897	93	204
4	14767	227	66
5	12552	271	149
6	17721	199	66

Table (3.3) {system C- Liquid} [44]

Stream no.	Cap. Flow rate (J/s.°C)	Tin(°C)	Tout (°C)
1	2.86×10^{6}	25	56
2	1.27×10^{6}	25	54
3	2.92×10^{8}	69	91

4	7.2×10^6	118	25
5	1.6×10^8	80	53
6	6.12×10^5	118	54

Design Data for the three systems (15, 16, 18, 20, 28, 29, and 44)

Table (3.4)

Steam (saturated) Pressure 6636 kN/m^2 (962.5 Ib/in^2.abs) for system A

282.2 ^oC (540 ^oF), λ=1527 KJ/Kg (656 Btu/Ib)

Steam (saturated) Pressure 3103 kN/m^2 (450.0 Ib/in^2.abs) for System B

235.7 ^oC (456 ^oF), λ=1785 kJ/kg (767.4 Btu/Ib)

Cooling Water Input Temperature T_{win}= 37.7 ^oC (100^oF)

Maximum Water Output Temperature T_{wout}= 82.2 ^oC (180 ^oF)

Minimum Allowable Temperature (ΔT_{lm}):-

-Heat Exchangers=11.1 ^oC (20 ^oF)

-Steam Heater = 13.88 ^oC (25 ^oF)

-Water Cooler = 11.1 ^oC (20 ^oF)

Overall Heat Transfer Coefficients

-Heat Exchangers=851.5 J/m^2.s.K (150 Btu/hr.ft^2. ^oF)

-Steam Heater =1135.4 J/m^2.s.K (200 Btu/hr.ft^2. ^oF)

-Water Cooler = 851.5 J/m^2.s.K (150 Btu/hr.ft^2. ^oF)

Heat Transfer Cost Parameters a=350 , b=0.6

Annual rate of return: δ=0.1

Cooling Water Cost C_C=2.267×10^{-5}\$/kg (5*10^-5 \$/lb).

Steam Cost C_s=1.2247×10 \$/kg (2.7*10^-3 \$/lb).

3.4. Assumptions of the heat exchanger networks:

The assumptions used in this work are:

1. For the shell and tube heat exchanger, counter current flow is assumed and single pass flow when the multiple passes are used to achieve the desired velocity on the tube side. In a single pass heat exchanger, the fluid on the tube side flows through half of the tubes in one direction and then flows back through the other half of the tubes in the other direction [12].

In this work a single –pass flow was chosen for the heat exchanger, which is most commonly used [8, 10, 18, and 19].

2. There are two cases about the phase of the fluid in the exchanger; first if there is no change in phase of process streams which leads to constant heat capacity, and the second case, the phase is changed in process streams, that means the heat capacity is also changed .In this work the first case is considered [20, 22, 23].

3. Equal values for the effective heat transfer coefficients for all the exchangers are assumed [15, 28].

4. Each stream is required to exchange heat once and only once [15, 28].

5. Stream splitting; the idea of stream splitting is dividing an existing stream between two exchangers, and thus perhaps using it more efficiently. Splitting can improve the performance of an energy recovery system. Most systems do not consider this aspect explicitly although the initial statement of the problem can be changed by manually splitting streams prior to energy recovery. Stream splitting may be employed to reduce the number of exchangers. No stream splitting considered in this work as in most references (5, 22, 24, 25, and 27).

6. The Log Mean Temperature Difference (LMTD) is assumed to be 11.1^oC (20 ^oF) in this work, as it is taken in most references [1, 8, 14, 26, 27 and 44].

3.5. Heat Exchanger Networks Methods: -

In the present work, the heuristics method which is considered first was that given by Rudd [16], Lee et al. [18],Nishida et al. [15,28] and Linnhoff [10], the second was the temperature interval method and the third was the pinch analysis method, that was studied by different workers to formulate the heat exchanger networks.

3.5.1. Heuristics Method:-

3.5.1.1. Lee, Rudd, and Masso Heuristic [18]:-

This heuristic depends on matching the first hottest hot with the first hottest cold and the second hottest hot with the second hottest cold and so on, until all the streams were matched, or the first coldest hot with the first coldest cold and the second coldest hot with the second coldest cold, etc. Because of its matching the number of combinations obtained was so limited, and certainly include the optimum.

3.5.1.2. Nishida, Kobayashi, and Ichikawa Heuristic [15, 28]: -

This heuristic gave a lot of combinations, these combinations came from the matching of i, j hot streams and i, j cold streams, then consider a permutation of (S_{hi}, S_{ci}), (S_{hj}, S_{ci}), (S_{hi}, S_{cj}), (S_{hj}, S_{cj}), where this matching enable each hot stream to connect with each cold stream once in every possibility .The number of combinations obtained from this heuristic is larger than that obtained by another heuristic.

3.5.1.3. Linnhoff, Flower Heuristic [10]:-

It is a systematic method with four steps for the networking. In this heuristic the streams must be ranked in decreasing order according to its capacity flow rate. And then the first hot can be matched with first cold, second hot with second cold, and so on. The largest remaining stream can be matched with the largest residual of the primary matches, the second largest remaining with the second largest residual, etc., whatever remains after these steps, that is, original streams, primary residual or secondary residuals, etc., the final step is to match these against utilities. This heuristic gives a single design, which may be quite far from the minimum structure cost or it may be near the minimum structure cost, or exactly represent it.

The details for these heuristics are given in appendices B1, B2.

3.5.2. Temperature Interval Method:-

The first step in the TI method is to adjust the source and target temperatures using ΔT_{min}. Somewhat arbitrarily, this is accomplished by reducing the temperatures of the hot streams by a ΔT_{min} while leaving the temperatures of the cold streams untouched. Then the adjusted temperatures are rank ordered beginning with T_o. The highest temperature and T_1, T_2 and so on, these temperatures where used to create a cascade of temperature intervals within which energy balances are carried out. Each interval (I) displays the difference ΔH_i between the energy to be removed from the hot streams and the energy to be taken up by the cold streams in that interval, that ΔH_i can be found by:

$$\Delta Hi = m \cdot Cp \cdot \Delta T \qquad \ldots\ldots (3.1)$$

When the values of enthalpy change for each interval was found, the pinch temperature must be found, which is the temperature at which no heat transfer across through it, in other meaning when the sign of ΔH was changed from a negative sign to a positive sign. This temperature represents the pinch for the cold streams, while the pinch for the hot represent the pinch for the cold plus the log mean temperature difference.

The hot streams are denoted by arrows from left to right; cold streams denoted by arrows moving from right to left. The arrows for the hot and the cold streams either pass through or begin at the pinch temperatures. To maintain minimum utilities, two separate HENs must be designed, one above and one below the pinch temperatures. Energy is not permitted to flow across the pinch .Energy is added from hot utilities above the pinch, and energy is removed using cold utilities below the pinch. If energy were exchanged between a hot stream above the pinch and a cold stream below the pinch, this energy would not be available to heat the cold streams above the pinch and additional energy from the hot utilities would be required .Similarly, the cold stream below the pinch would not have the ability to remove this energy from the hot streams below the pinch and the same amount additional energy would have to be removed from the cold streams below the pinch using cold utilities. In other words, where energy flows across the pinch, the energy transferred from or to the hot and cold utilities must be increased by this amount.

To match the streams while maintaining the minimum utilities the streams above and below the pinch are examined. When the matching between these streams is done depending on the value of the capacity flow rate, the highest capacity flow rate hot stream can be matched with the highest capacity flow rate cold stream, and so on, until all the streams are matched. The network below the pinch contains no coolers, just steam heaters, while the network above the pinch contains coolers. System C, table (3.3) was taken to be solved by this method [12].

3.5.3. Pinch Analysis:-

The first step in the energy integration analysis is the calculation of the minimum heating and cooling requirements for a heat exchanger network. In any process flow sheet, there are several streams that need to be heated and other to be cooled; there are two laws for each heat integration analysis. The first law states that the difference between the heat available in the hot streams and the heat required for the cold streams is the net amount of heat which must be removed or supplied .The heat associated with each stream can be calculated by using the following equation :-

$$Q = m \cdot Cp \cdot \Delta T \min \qquad \text{..... (3.2)}$$

In this work, system C {table (3.3)} was considered; there are three streams to be cooled and three to be heated up. The first calculations are to find the available heat, then calculate the net heat that must be supplied from utilities if no restrictions on temperature –driving forces are present. However, the calculations for the first law do not consider the fact that heat can only be transferred from a hot stream to a cold stream, if the temperature of the hot streams surpasses that of the cold stream. Therefore, the second law states that a positive temperature driving force must exist between the hot and cold streams. For any heat exchanger networks, the second law must be satisfied as well as the first law. The minimum driving force temperature was taken to be 11.1^{o}C {20 ^{o}F} between the hot and cold streams; this value is the suitable for such process as it was taken by most references. A graph can be established showing two temperature scales that are shifted by a ΔT_{min}, one for the hot streams and the other for the cold streams. Then, stream data is plotted on this graph. Next a series of temperature intervals are generated corresponding to the heads and the tails of the arrows on the graph.

In each interval, heat from any hot streams in the high –temperature can be transferred to any of the cold streams at lower –temperature intervals. For a starting point, heat transfer in each interval would be considered separately. The necessary equation is shown below:-

$$Q=\left[\sum(FCp)hot,i-\sum(FCp)cold,i\right]\cdot\Delta Ti \qquad \text{…..(3.3)}$$

The summation of the heat available in all the intervals is the same as the net difference between the heat available in the hot streams and that in the cold streams obtained using the first law. After finding the heat for each interval represent in a diagram, which is called cascade diagram (shows the heat cascades through the temperature intervals). From this diagram the total minimum heating and cooling loads were calculated which have now been fixed to satisfy the second law. It is observed from the cascade diagram that there is no transfer of energy in some point in the diagram .This point is called a pinch point [(44)].

The temperature –enthalpy diagram must be constructed, the minimum heating and cooling loads were calculated by the above procedure. Then the enthalpy corresponding to the coldest temperature of any hot stream will be defined as the base condition: i.e. H=0 at the coldest temperature of any hot stream .The next step is to calculate the cumulative heat available in the sum of all the hot streams moving from lower to higher temperature intervals. Then we plot the hot streams temperature versus the cumulative H. To give the hot composite curve, this includes the effect of all the hot streams. Similarly for cold composite curve for the cold streams can be created by calculating the cumulative enthalpy of each cold stream.

Another useful diagram is the grand composite curve. To prepare this curve, begin with the pinch temperature assigning zero value to it. The calculation procedure for this curve is by finding the mean temperature and then the total heat flow. The figures contain these curves and the calculations of total heat flow were given in chapter four and in appendices B1, B3. If the minimum heating and cooling energy requirements and the number of heat exchangers were known, the appropriate procedure is to design two sub networks of exchangers –one above the pinch and one below it. The design above the pinch can be done by determining the inlet and outlet temperatures for each stream. Then calculate the heat load for each stream at the pinch temperature and match a hot stream of highest capacity flow rate with the cold stream of highest capacity flow rate. The heat load remaining from the hot stream is determined by subtracting heat load of each of the cold stream from the hot stream. The temperature can also be determined after each matching. The design procedure below the pinch consists of determining the minimum number of exchangers below the pinch temperature is analogous to that of above the pinch. The difference is that we can only allow rejecting heat to a cold utility. Therefore; coolers are used instead of heat exchangers, where the amounts of heat remaining from each stream are cooled using utilities (22). Table (3.3) shows system C, which is chosen to be solved by this method, the details is given in appendix B3.

3.5.3.1. Reducing the number of exchangers:-

Reducing the number of exchangers will definitely lower the cost for equipment (capital cost). However it will increase the cost of utilities (operating cost) .Therefore; the main objective of this stage is to search for the lowest annual cost for our exchanger network. The number of heat exchangers required for the overall process is always less than or equal to that for a minimum energy network. This can be done by equation below (44):

(Number of Heat Exchangers)= (Number of Streams) + (Number of Utilities)-(Number of Independent problems) …..(3.4)

This will be clear in the results. Appendices B1, B3.

3.6. Heat Exchangers Network Calculations:-

In most analysis, at any stage in process creation, it is common initially to disregard power demands in favor of designing an effective network of heat exchangers by heat integration, without using the energy of the high – temperature streams to produce power. To accomplish this, M hot streams with specified source and target temperatures. T_{hi} and T_{ho} ,i=1,…….,M , are to be cooled by N cold process streams ,with specified source and target temperatures T_{ci} and T_{co} ,J=1,….,N . Because the sum of heating requirements does not equal the sum of the cooling requirements and some source temperatures may not be sufficiently high or low to achieve some target temperatures, it is always necessary to provide one or more auxiliary heat exchangers for heating and cooling through the use of utilities such as steam and cooling water. It is common to refer to the heat exchangers between the hot and cold process streams as comprising, the interior network and those between the hot and cold streams and the utilities as comprising the auxiliary network..

When carrying out the design, the states of the source and target streams such as (flow rates of the species, temperature, pressure, and phase) must be given.

The calculation for the network is represented by evaluating the specific parameters for each exchanger; these parameters are the heat duty (Q) which can be found by:

$$\mathbf{Q=U.A.\Delta T_{\mathit{lm}}} \qquad \text{…. (3.5)}$$

The area is estimated by

$$A = \frac{Q}{U \cdot Ft \cdot \Delta Tlm} \qquad \text{…. (3.6)}$$

Where F_t is the correction factor for a multiple –pass exchangers, and ΔT_{lm} is the logs mean temperature difference at the two ends. Equation 3.2 must be used with care because of its restrictions. If both phase change and significant temperature change occur for one or both streams U is not constant and ΔT_{lm} is not appropriate. In many cases, multiple – pass exchangers are necessary for which F_t in the range 0.75-0.9. Nevertheless, for the purpose of developing a reasonably optimal heat exchanger network, it is common to apply equation (3.2) With F_t =1.0.

ΔT_{lm} is estimated by:

$$\Delta Tlm = \frac{[(Thi - Tco) - (Tho - Tci)]}{\ln\left[\frac{(Thi - Tco)}{(Tho - Tci)}\right]} \qquad \text{…. (3.7)}$$

3.6.1. Cost Calculations:-

The cost of heat exchanger, heater, cooler, can be calculated as a function of its area of exchange by a cost correlation such as:

$$Cost = a \cdot (A)^{\wedge} b \qquad \text{….. (3.8)}$$

Where a and b, the cost parameters given in the design data table (3.4).These Correlations usually yield good estimates of heat exchanger costs (16,18,19,20, 28, and 31).

The individuals' costs for each exchanger must be calculated.

Total Cost for the heat exchangers:-

$$CEi = \sum a \cdot AEi^{\wedge} b \qquad \text{….. (3.9)}$$

Total cost for the coolers:-

$$Cci = \sum a \cdot Aci^{\wedge} b \qquad \text{….. (3.10)}$$

Total cost for the heaters:-

$$Chi = \sum a \cdot Ahi \wedge b \qquad \text{...... (3.11)}$$

The utilities cost:-

$$U = \left[\sum Cs + \sum Cw\right]$$

The details of the utilities cost are given in appendix A.

The total heat exchanger network cost is:-

$$J = \delta\left[CEi + Cci + Chi\right] + U \qquad \text{...... (3.12)}$$

Where δ=0.1 (table 3.4)

The details for cost estimation are given in appendix A, and samples of calculations are given in the results chapter.

Chapter Four

RESULTS AND DISCUSSION

4.1. Introduction

The analysis of heat exchanger network was considered, in this chapter the final results of networking using heuristics, temperature interval method and pinch analysis methods were obtained using a developed computer program.

The discussion of the results and a comparison between the networking methods used were considered, to give the difference and similarity between these methods.

A comparison between this work and the other previous works were considered. The effect of changing the minimum allowable temperature (ΔT_{min}) was studied to see the influence of this parameter on the network design.

4.2. The Results of the Networking Methods:

The three systems chosen were solved by the three methods and the results were given below:

4.2.1. The Results of the Heuristics Method

4.2.1.1. System A

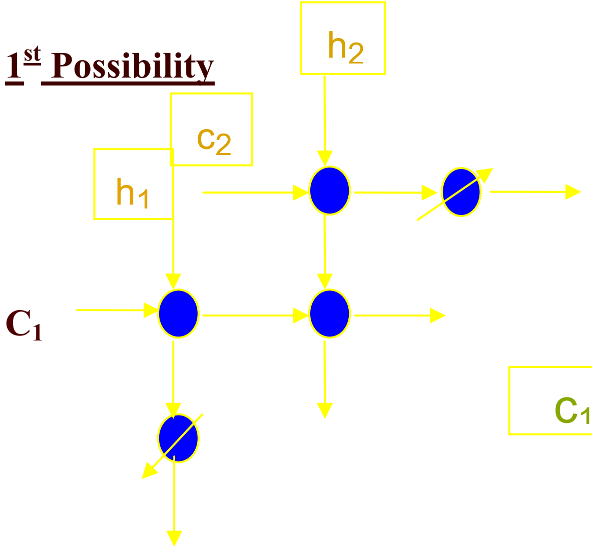
System A with four streams consists of two cold and two hot streams which can be matched in different ways depending on the heuristic law, in order to find the minimum cost structure.

a. Applying Lee, Masso and Rudd [16, 18] heuristic on system A

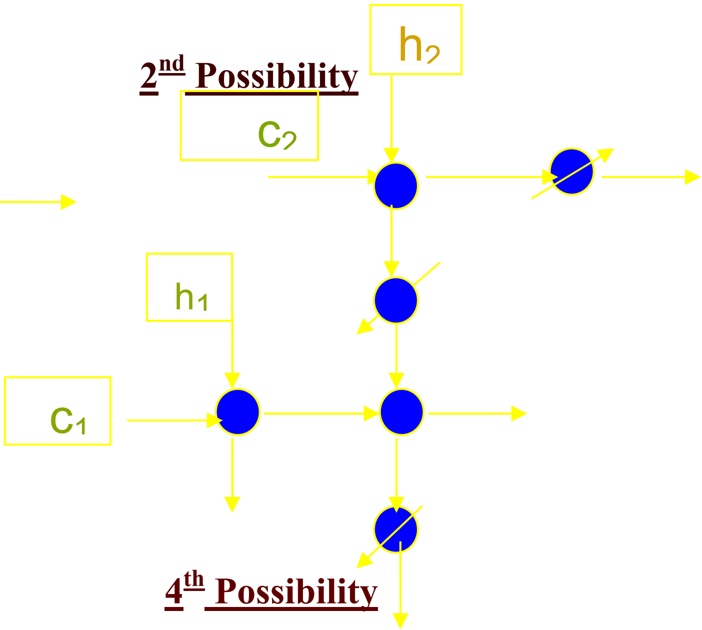
The matching by this heuristic is done by connecting the 1st hottest hot (249 ^oC) with the 1st hottest cold (116 ^oC) and the 2nd hottest hot (160 ^oC) with the 2nd hottest cold (60.0 ^oC). Four networks were obtained by this matching with different utilities number and location.

These networks with their costs and areas are given in table (4.1):

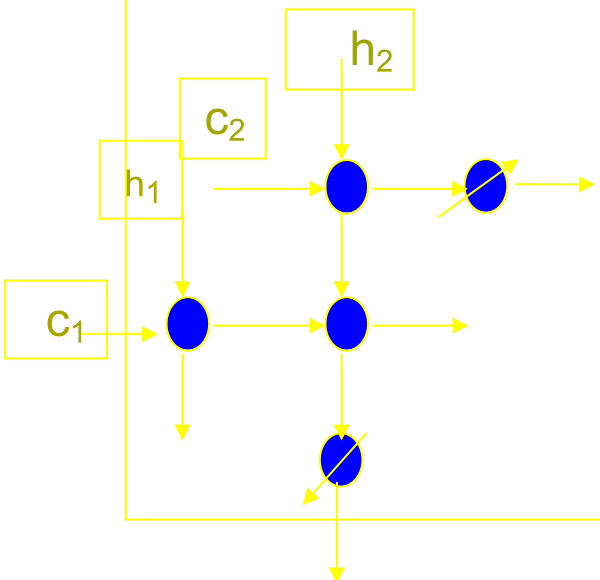
1st Possibility



2nd Possibility



3rd Possibility



4th Possibility

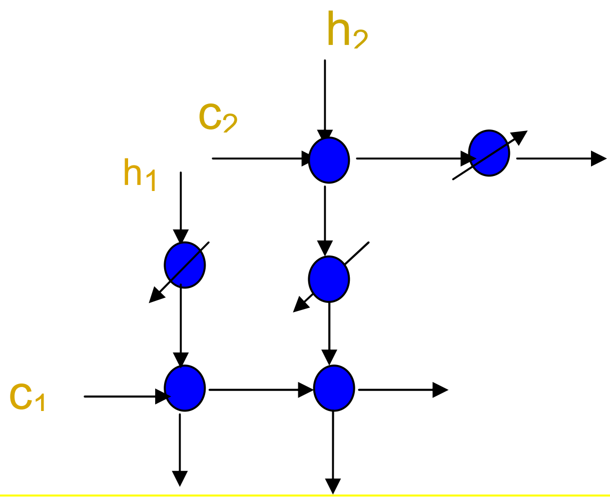


Table (4.1): System A by Rudd heuristic

Cost (ID/y)	Area (m^2)
36.60×10^6	112.04
36.25×10^6	112.03
38.08×10^6	117.22
366.0×10^6	112.56

*Where represent heater represent cooler heat exchanger

*the hot streams enter the exchanger at the top (shell) and the cold one enter at the left side(tube).

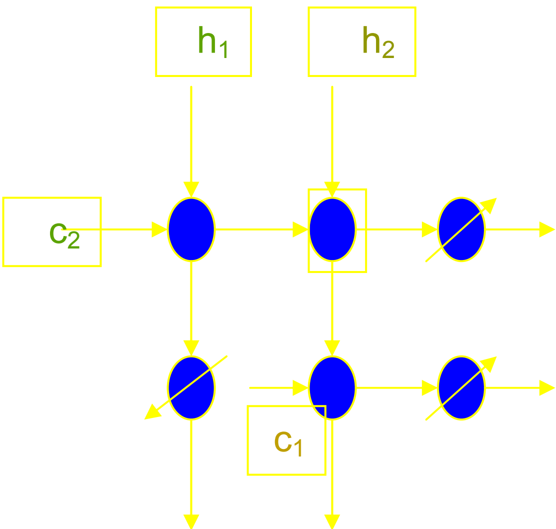
The details of the calculations for these networks are given in appendix B1.

b. Applying Nishida, Kobayashi, and Ichikawa heuristic [15, 31]:

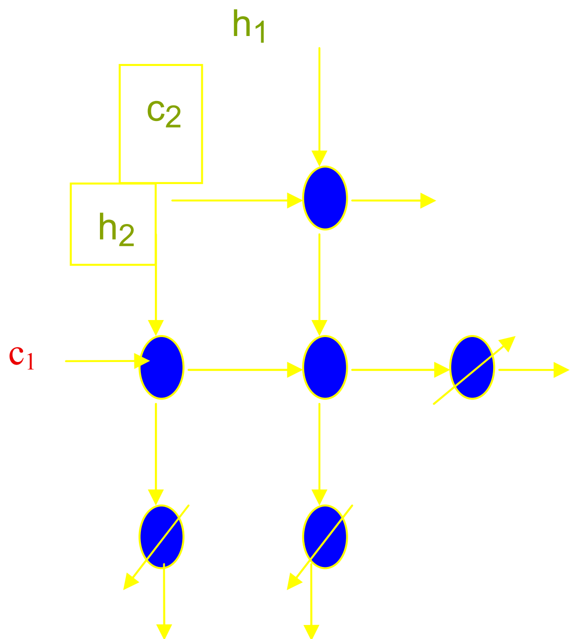
This heuristic gives a number of combinations which is more than that obtained by first heuristic. The matching is done by connecting the 1st hot stream (249 °C) with the 1st cold stream (116 °C), and connecting the 2nd hot (160 °C) with the 2nd cold (60.0 °C) in the first possibility. In the other possibility connect (249 °C) with (60.0 °C) and (116 °C) with (160 °C). This gives many networks that have the same matching, but differ in utilities number and location.

For system A using this heuristic {8} possibilities were obtained. These possibilities with their cost and area are given in table (4.2), while the details for the design calculations are given in appendix B1.

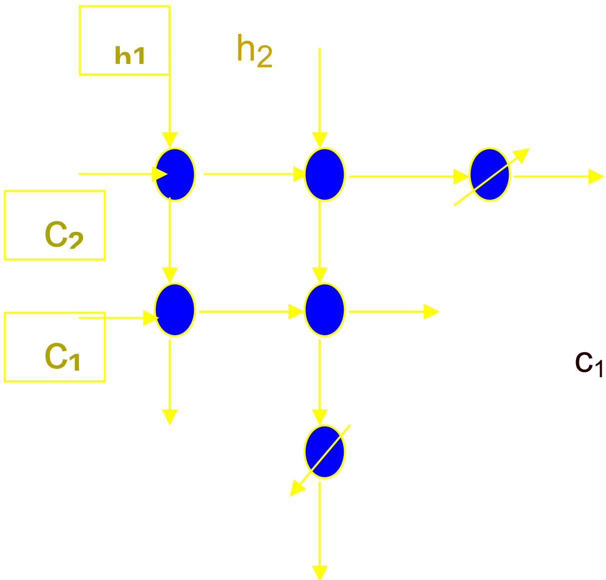
1st Possibility



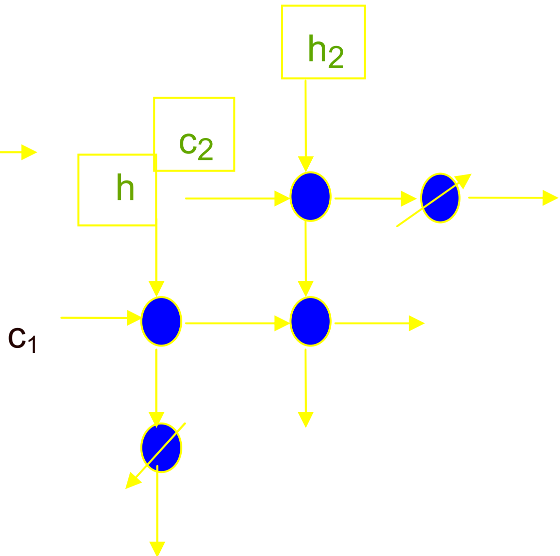
2nd Possibility



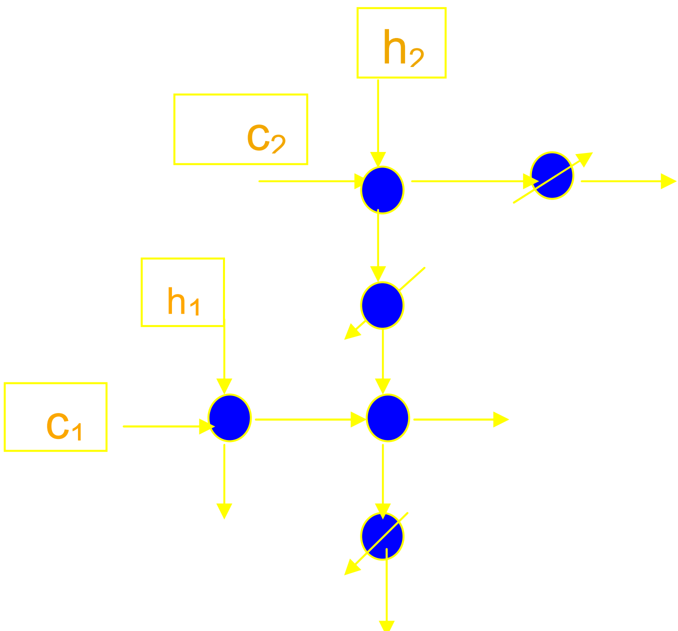
3rd Possibility



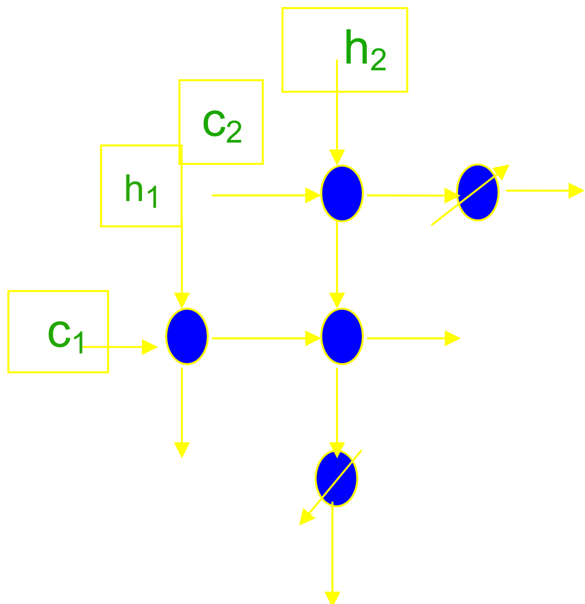
4th Possibility



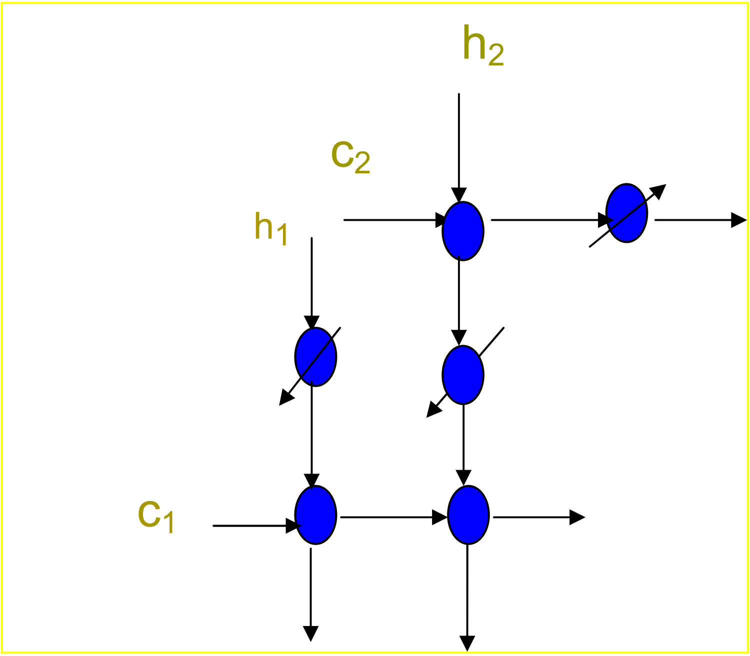
5th Possibility



6th Possibility



7^{th} Possibility



8^{th} Possibility

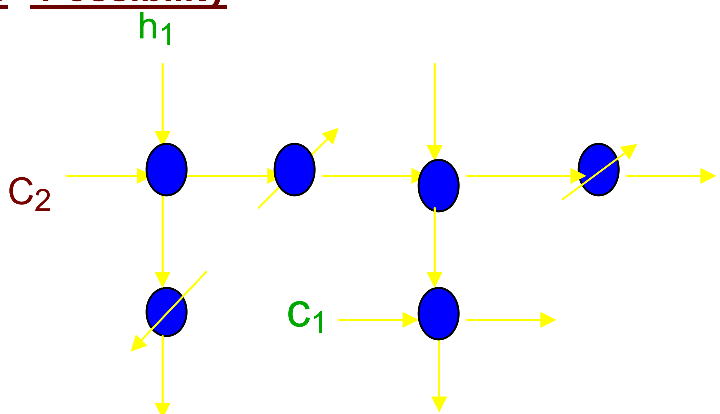
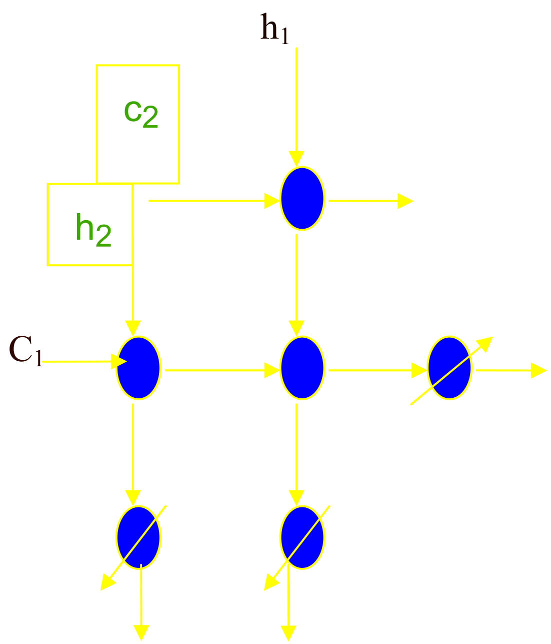


Table (4.2): The costs and areas values for system A obtained by Nishida

Possibility number	cost (ID/y)	Areas (m^2)
J1=	65.58×10^6	290.0
J2=	113×10^6	721.0
J3=	371.7×10^6	112.6
J4=	36.2×10^6	112.03
J5=	36.64×10^6	112.06
J6=	38.08×10^6	117.2
J7=	36.6×10^6	112.5
J8=	64.3×10^6	280.74

c. Applying Linnhoff and Flower Heuristic [10]:

This heuristic gives one structure, this structure is made by connecting the first hot (249 °C) with the first cold (60.0 °C), after ranking the streams in descending order according to its capacity flow rate. Connect the second hot (160 °C) with the second cold (116 °C). In system A, the structure with its cost and area are given below.



J=	113.2×10^6	ID/y
A=	721	m^2

Appendix B_1 gives the calculations details.

4.2.1.2. System B

A six streams system consists of three hot and three cold streams, which can be matched in different ways, depending on the heuristic, in order to find the minimum cost network structure.

a. Applying Lee, Masso and Rudd [16, 18] heuristic:

In this heuristic we Connect the 1st hottest hot stream (271°C) with the 1st hottest cold stream (93 °C), and the 2nd hottest hot stream (227 °C) with the 2nd hottest cold stream (83°C) and the 3rd hottest hot (199°C) with the 3rd hottest cold stream (37 °C), which gives five possibilities similar in stream matching, and differs in the number of utilities and in utilities location.

The possibilities obtained by this method with their details of calculations are given in appendix B_2, their costs and areas are given in table (4.3).

Table (4.3): The costs and areas values obtained by Rudd for system B.

Possibility Number	Cost (ID/y)	Area (m^2)
1	108.0×10^6	672.9
2	119.7×10^6	790.8
3	107.6×10^6	662.06
4	109.0×10^6	706.26
5	115.7×10^6	679.44

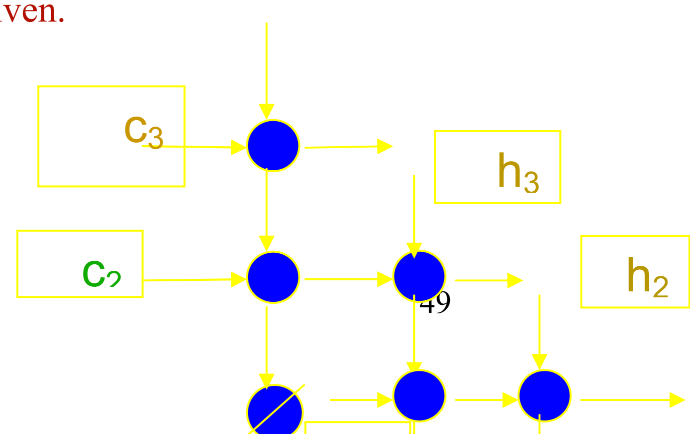
b. Applying Nishida, Ichikawa, and Kobayashi [15, 28] heuristic:

The number of combinations obtained by this heuristic is 25 possibilities; these properties obtained by connecting the 1st hot with 1st cold, 2nd hot with 2nd cold, and 3rd hot with the 3rd cold. This matching will give a number of possibilities; another matching is done by connecting the 1st hot with the 2nd cold instead of the 1st cold, and so on until all possible ways of matching were taken. Table (4.4) shows the costs and areas for each possibility and the details of calculations are given in appendix B_2.

Table (4.4): The costs and areas values for system B obtained by Nishida.

Possibility number	Cost (ID/y)	Area (m^2)
1	58.17×10^6	237.5
2	171.3×10^6	1437.4
3	241×10^6	2545.4
4	106.2×10^6	648.4
5	88.0×10^6	473.5
6	100.0×10^6	586.6
7	101.2×10^6	597.7
8	87.0×10^6	464.7
9	108.6×10^6	672.9
10	110.0×10^6	692.2
11	82.1×10^6	312.9
12	119.7×10^6	790.8
13	142×10^6	1060.2
14	156.2×10^6	1232.2
15	58.72×10^6	241.2
16	92.3×10^6	513.0
17	58.6×10^6	240.51
18	108.9×10^6	675.41
19	113.2×10^6	726.17
20	107×10^6	662.0
21	608.3×10^6	255.8
22	106.0×10^6	591.66
23	109×10^6	706.26
24	124.5×10^6	918.46
25	115.7×10^6	679.44

c. Applying Linnhoff Heuristic [10]: This heuristic was applied on system B, one structure will obtained which is given below; its cost and area are also given.



$J=60.8\times10^6$ ID/y

$A=255.8\ m^2$

The details of calculations are given in appendix B2.

4.2.1.3. Results of Temperature Interval Method:-

This method was applied on system A and system C (table 3.3) with three hot and three cold streams. It gives one structure which can be calculated by adjusting the temperature of hot streams by $\Delta T_{min}=11^{o}$ C, then ranked the temperature in descending order.

a. System A

The adjusted temperatures for system A are calculated and given in table (4.6).

Table (4.6): The adjusted temperatures for system A

C1	140	320			
			140		T7
				320	T2
C2	240	500			
			240		T5
				500	T0
H1	320	200			
			300		T3
				180	T6
H2	480	280			
			460		T1
				260	T4

The cascade diagram was constructed by these adjusted temperatures and the pinch temperature was calculated which are equal to 460° F for cold streams and 480° F for hot streams. Figure (4.3)

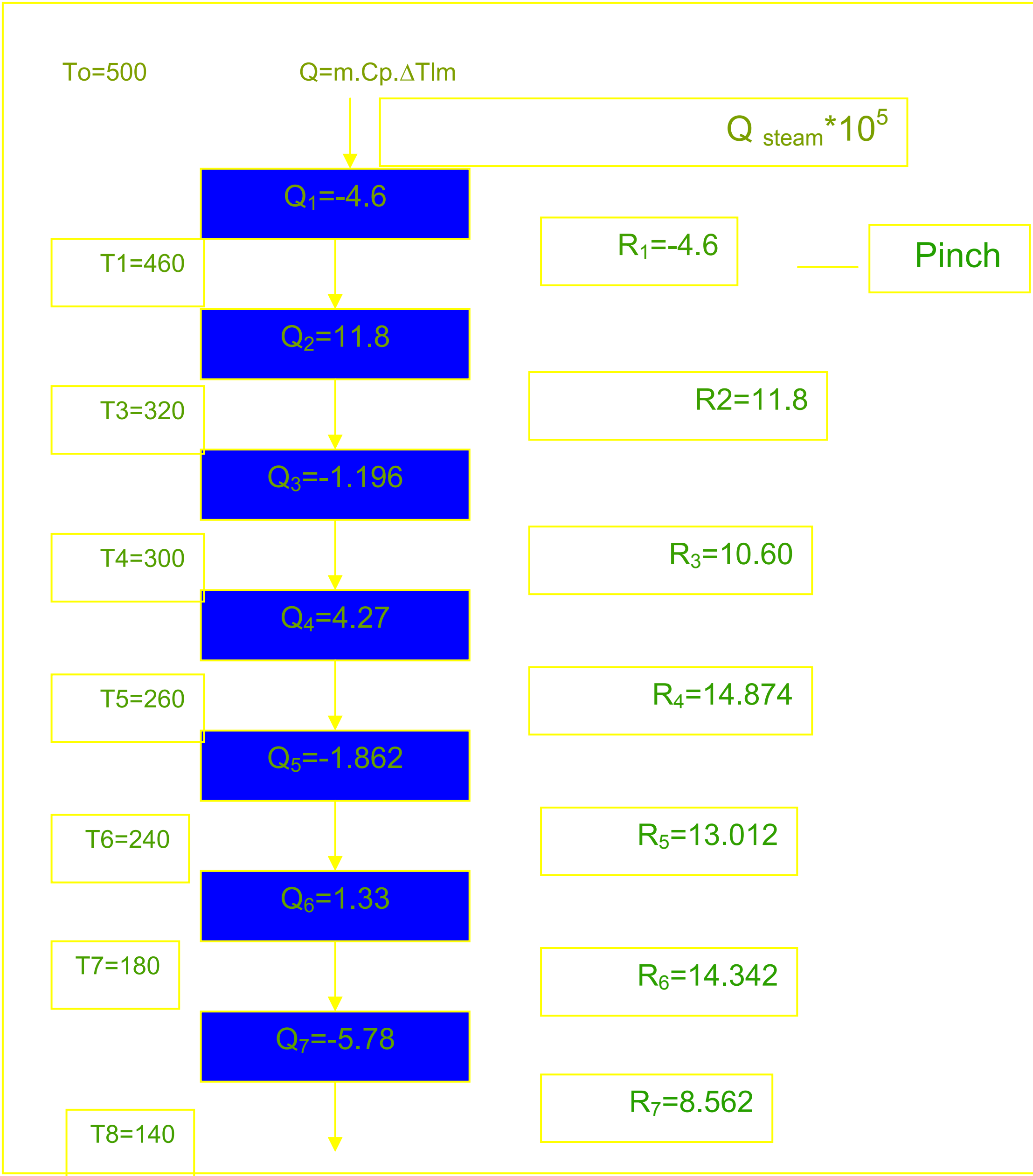


Figure (4.3): Cascade diagram for system A

The complete structure was found after finding the pinch temperature as in figure (4.4).

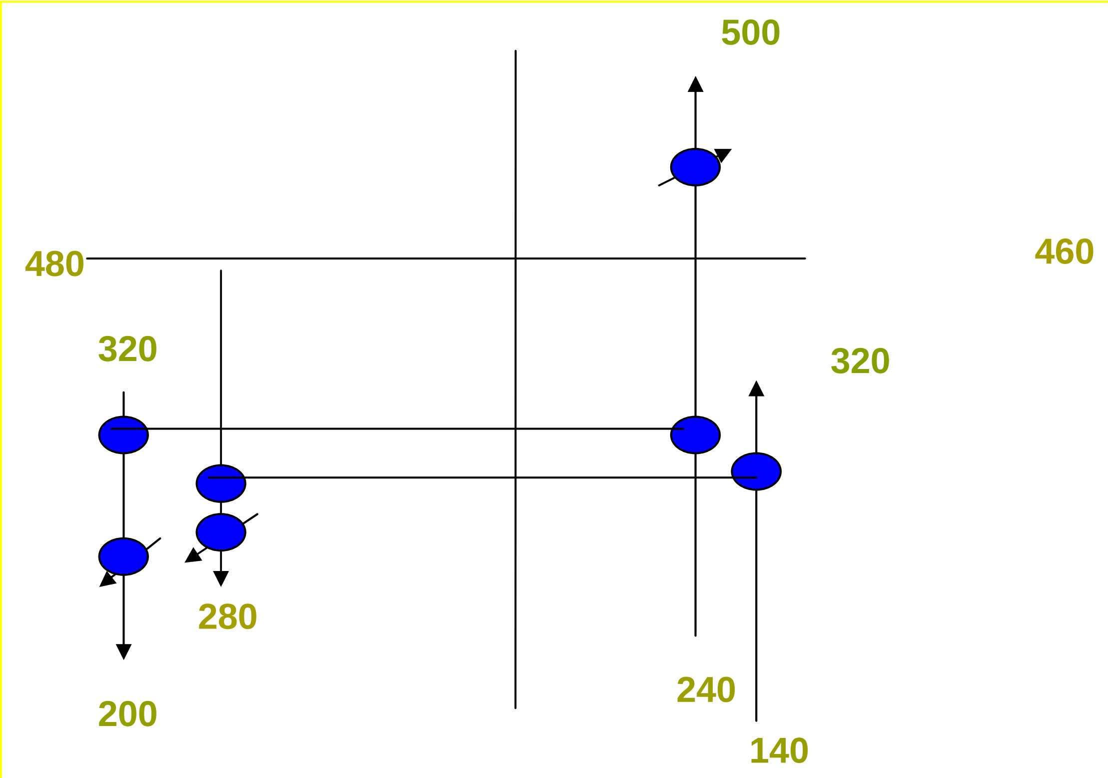


Figure (4.4): TI Structure for system A

J=	4.75×10^{6}	ID/y
A=	169.42	m^2

b. System C

Table (4.5): The adjusted temperatures for system C:-

C1	77	133			
			77		T7
				133	T3
C2	77	129			
			77		T7
				129	T4
C3	156	196			
			156		T2
				196	T1
H1	244	77			
			224		To
				57	T8
H2	176	128			
			156		T2
				108	T6
H3	244	129			
			224		To
				109	T5

Then according to this adjusted temperatures, the heat load for each interval was calculated as in cascade diagram figure (4.1). From this diagram the pinch temperature is 156 ^{o}F for cold streams and 176 ^{o}F for hot streams.

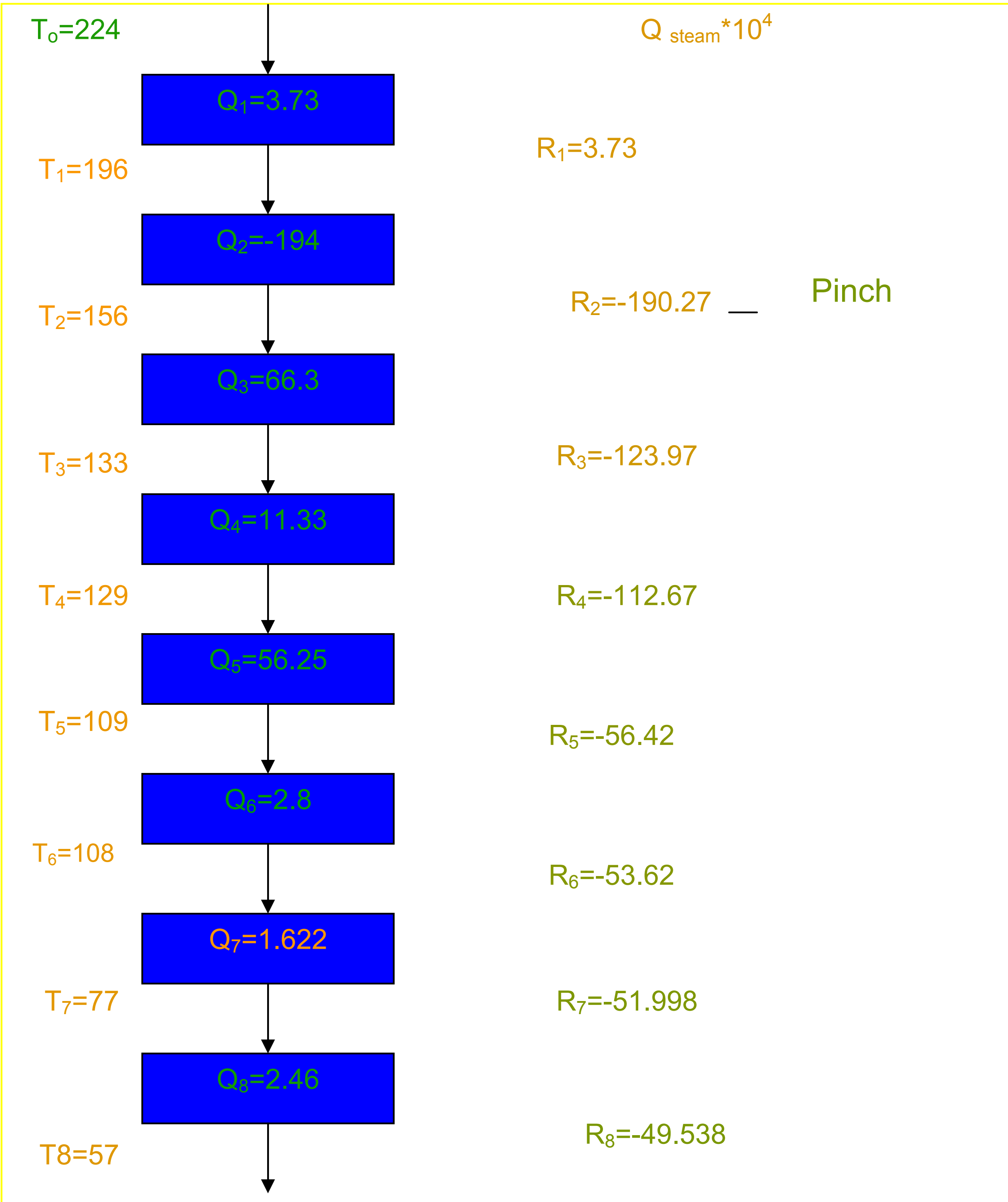


Figure (4.1): The cascade diagram for system C

The network was structured after knowing the pinch temperature, and matching was done by connecting the streams according to its capacity flow rate as in Linnhoff heuristic [(10)]. The network will be divided into two sub networks, one above and one below the pinch. The network above contains heating utilities and the one below contains cooling utilities. Then the calculation was done for each exchanger as in heuristics method. Figure (4.2) shows the structure obtained by this method after matching streams with its cost and area. The details of calculations are given in appendix B3.

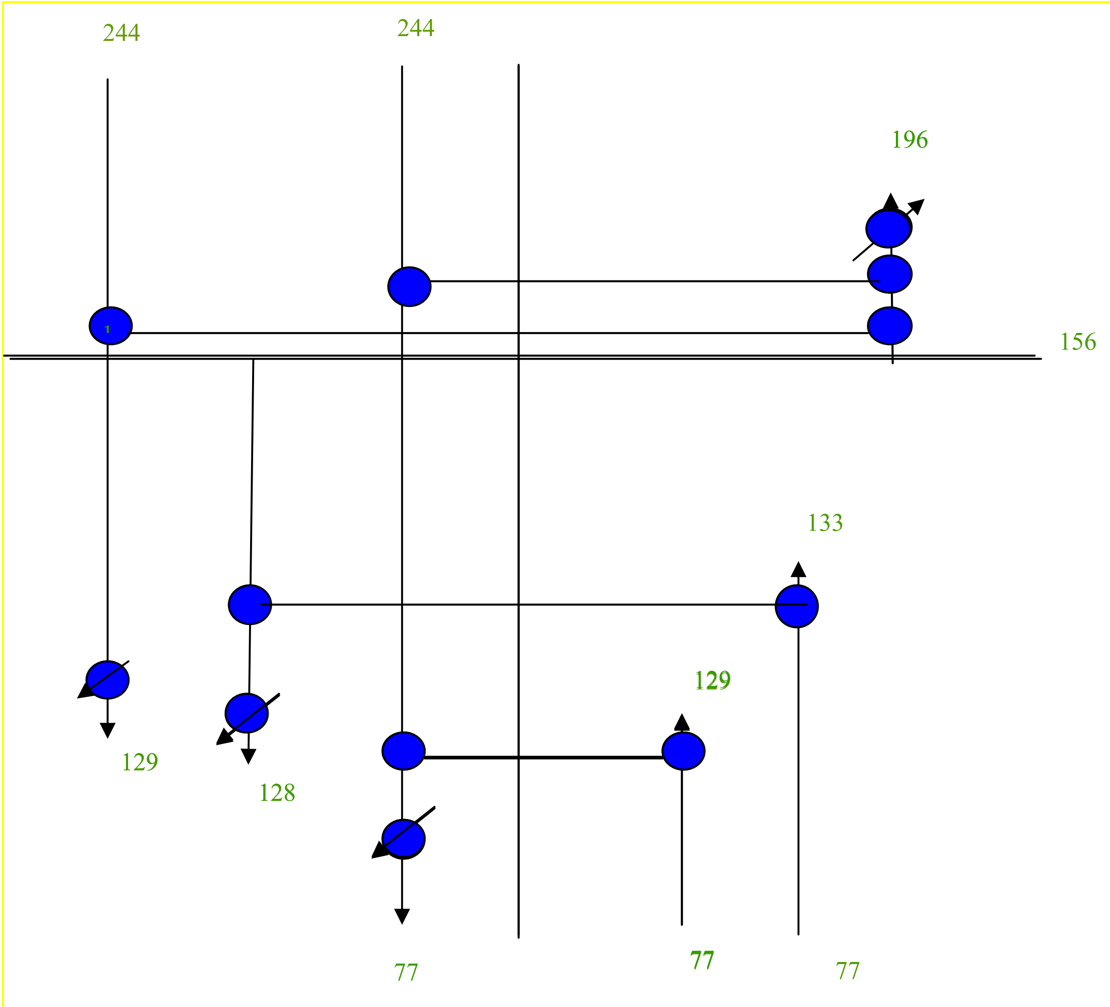


Figure (4.2): TI Structure for system C

COST=565×10^{6} ID/y

Area=10,520.6 m^{2}

4.2.3. Results of Pinch Analysis Method:-

System A and C were solved by pinch analysis, first the temperature intervals was drawn. After ranking the temperatures of streams, the energy for each interval can be calculated by summing the hot streams heat capacity flow rate available in this interval and subtract the summation of cold stream heat capacity flow rate and then multiply by the temperature difference for this interval.

4.2.3.1. System C

The temperature interval diagram for system C is shown in figure (4.6), then the cascade diagram was drawn, figure (4.1).

The enthalpy values and cumulative enthalpy for hot streams are then found starting with base condition H_o=0 at 77 ^oF. Table (4.7) shows the results of calculating the cumulative enthalpy for the hot composite curve and figure (4.6) shows the hot composite curve.

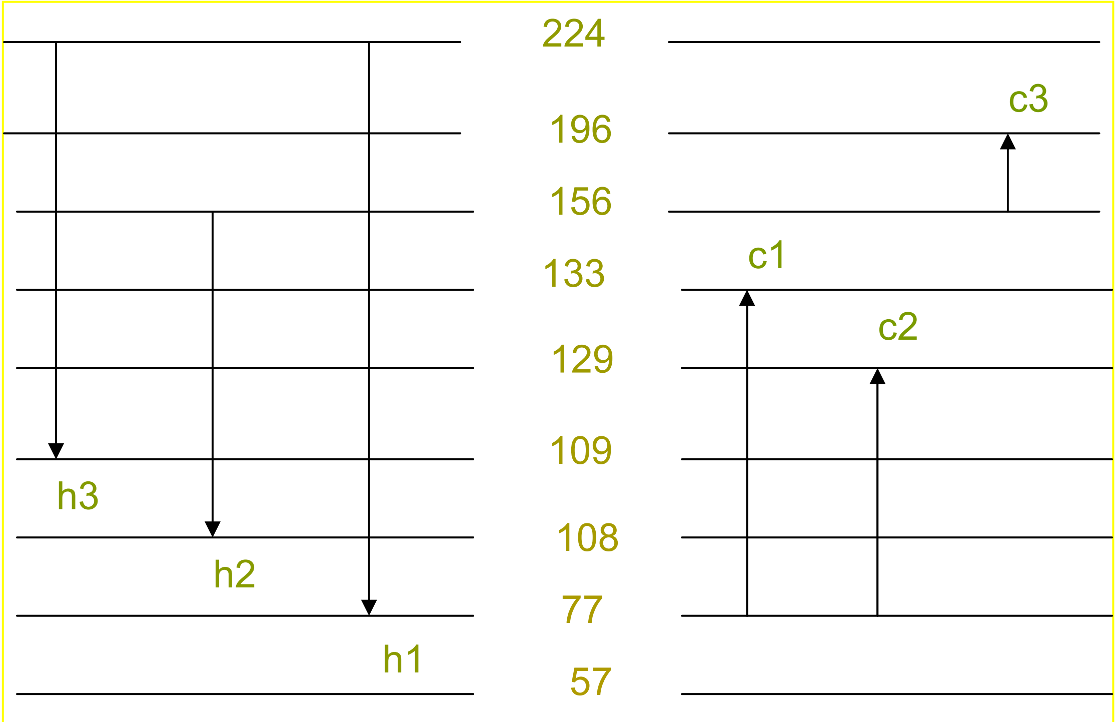


Figure (4.5): Temperature Interval diagram for system C

The cold composite curve was created by calculating the accumulative enthalpy of each cold stream. Table (4.8) gives the result for the cold composite curve and figure (4.7) gives the cold composite curve. The grand composite curve was drawn, which prepared by starting with the

Pinch temperature and assigning zero value to it. In the present work, the pinch temperature is 166 ^{o}F which comes from $\left(\frac{156+176}{2}\right)$. The average temperature is used to calculate the total heat flow. This curve data is given in table (4.9). Figure (4.8) gives the grand composite curve.

Table (4.7): Data for hot composite curve

Temp.	H	$H_{acc.}$
77	0	0
97	2.460×10^5	2.460×10^5
128	8.906×10^6	9.152×10^6
129	2.870×10^5	9.430×10^6
149	5.766×10^6	1.52×10^7
153	1.153×10^6	1.635×10^7
176	6.630×10^6	2.29×10^7
216	5.330×10^5	2.35×10^7
244	3.730×10^5	2.38×10^7

Table (4.8): Data for cold composite curve

Temp.	H	H acc.
77	162.87×10^5	162.87×10^5
108	2.19×10^5	1.65×10^7
109	7.06×10^3	1.651×10^7
129	1.41×10^5	1.66×10^7
133	1.95×10^4	1.665×10^7
156	0	1.667×10^7
196	2.00×10^7	3.667×10^7
224	0	3.66×10^7

Table (4.9): Data for Grand Composite Curve

Avg. tem.	H acc.
67	162.87
87	138.27
118	136.65
119	133.85
139	77.6
143	66.3
166	0
206	194
234	197.73

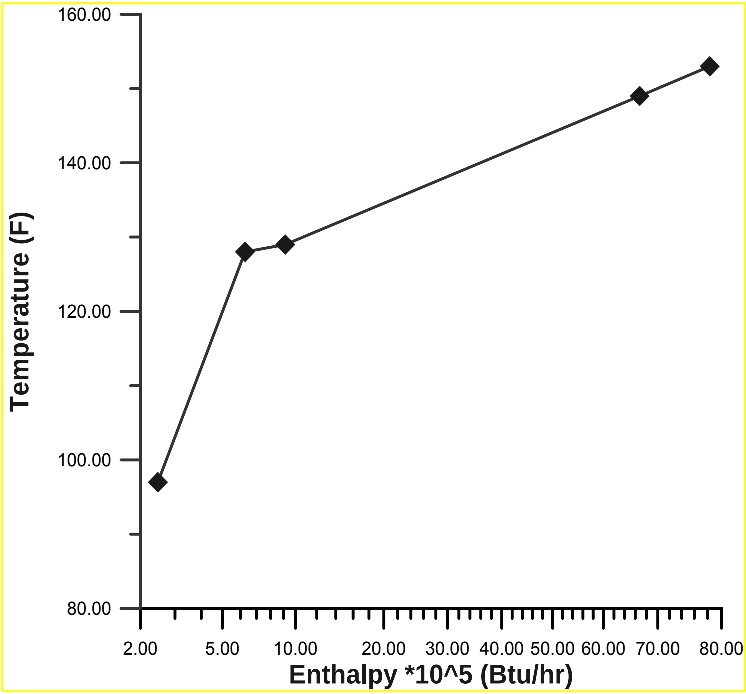


Figure (4.6): Hot Composite Curve for system C

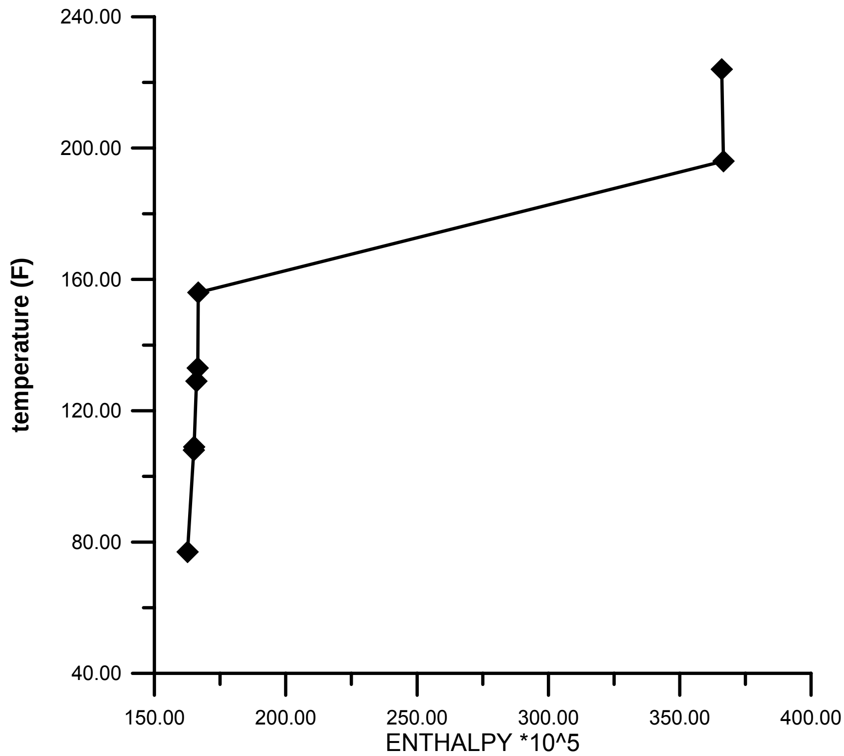


Figure (4.7): Cold Composite Curve for system C

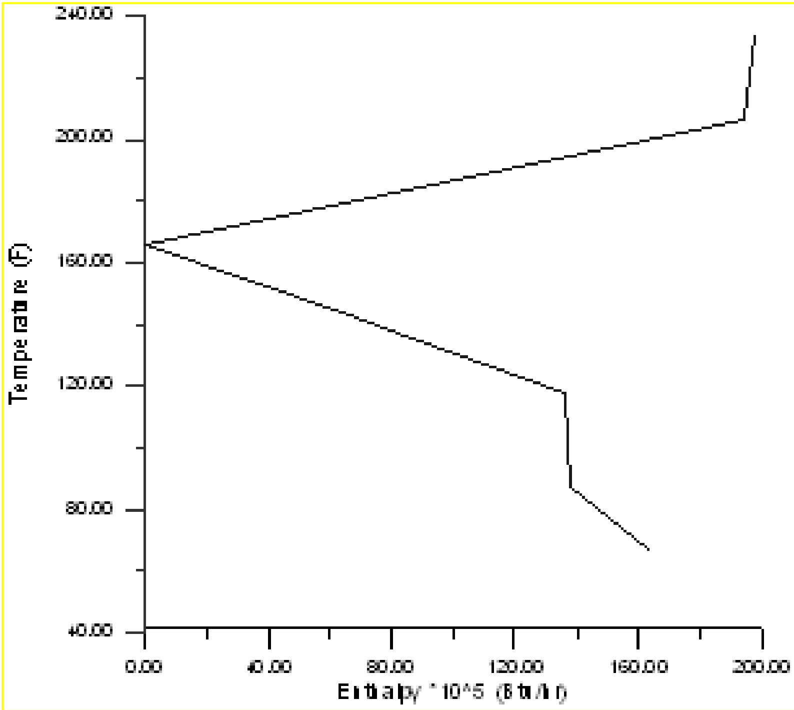


Figure (4.8): Grand Composite Curve For system C

Knowing the minimum heating and cooling energy requirements and the number of heat exchangers, the design of the heat exchanger network was done, the appropriate procedure is to design two sub networks of exchangers, above and below the pinch. The design above the pinch is done by determining the inlet and outlet temperatures of each stream and calculates the heat loads for each stream using the capacity flow rate value.

Then match the hot stream of the highest capacity flow rate value with the cold stream of the highest capacity flow rate value, the temperature of each matching was also determined. The design above the pinch is shown in figure (4.9) and the design below is analogous to that above with little difference that is there are heaters instead of coolers. Figure (4.10) shows the design and the details of these designs are given in appendix B3. Figure (4.2) gives the design obtained by the pinch method with area= 10529m^2 and cost =565×10^6 ID/y.

Number of Heat Exchangers is calculated using Equation (3.4), if these parameters were known:

-Original Number of Heat Exchangers=8

-Number of Streams=6

-Number of Utilities=4

-Number of Independent Variables=3

Then the reduced number of heat exchangers=6+4-3=7

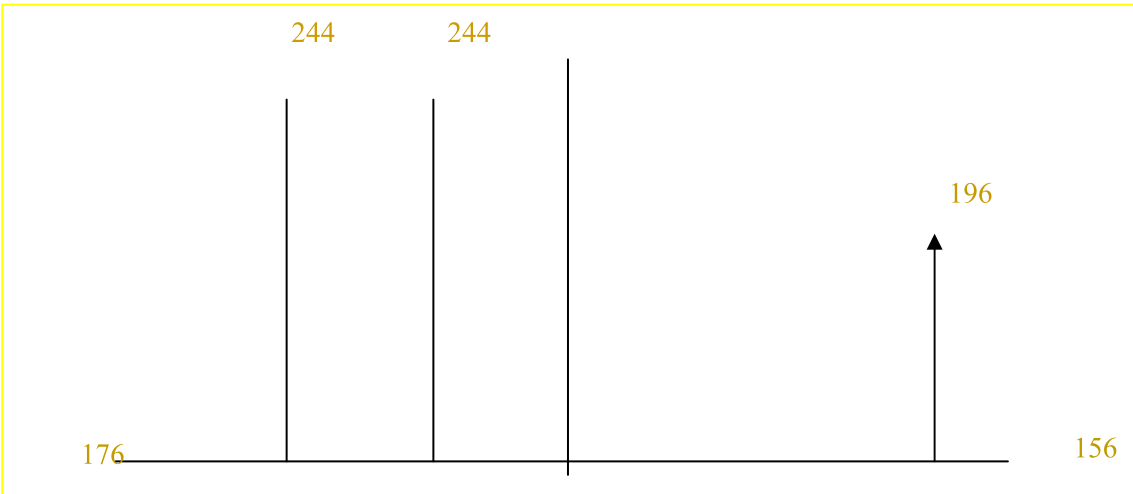


Figure (4.9): Design above the Pinch

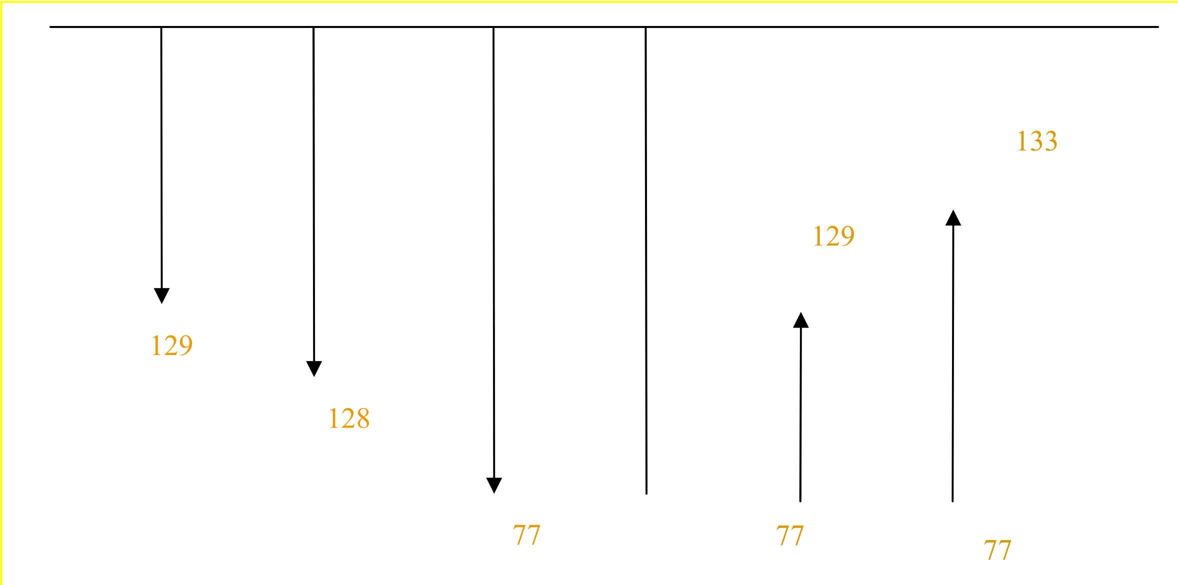


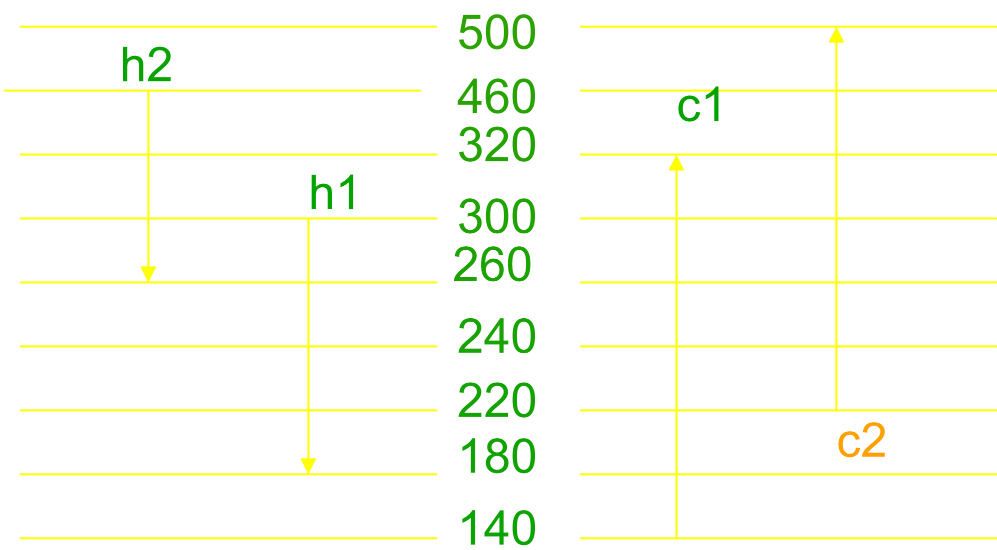
Figure (4.10): Design below the Pinch

4.2.3.2. System A:-

The heat intervals diagram was drawn in figure (4.11) and the cascade diagram is the same cascade diagram obtained by pinch analysis, figure (4.3). The hot and cold composite curves and the grand composite curves are given in figures (4.12), (4.13), (4.14).

Figure (4.11)

Temperature Interval diagram



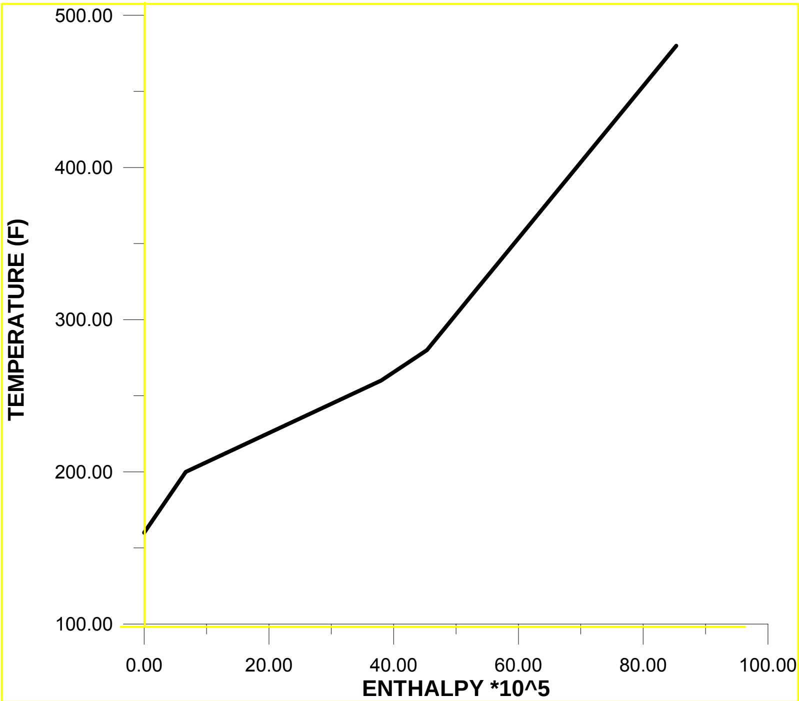


Figure (4.12): Hot Composite Curve for system A

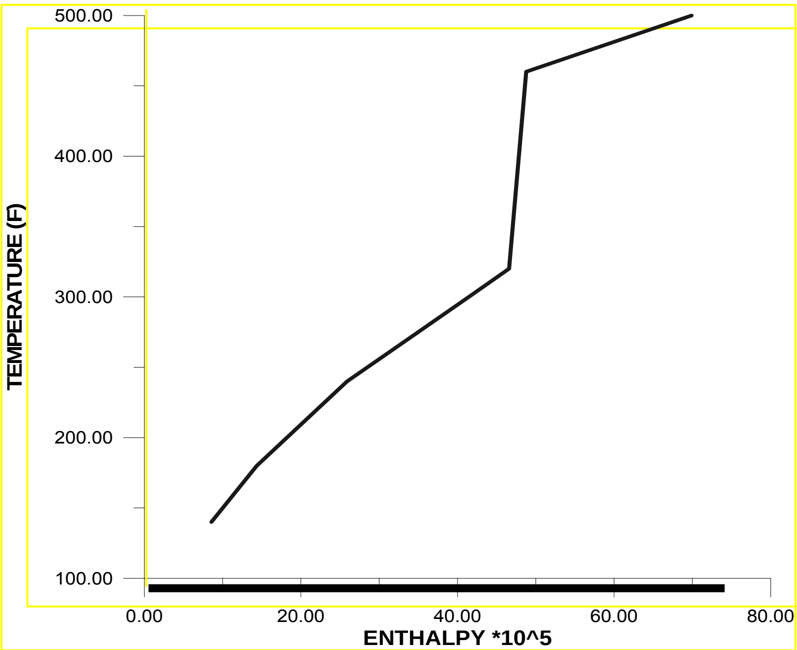


Figure (4.13): Cold Composite Curve for system A

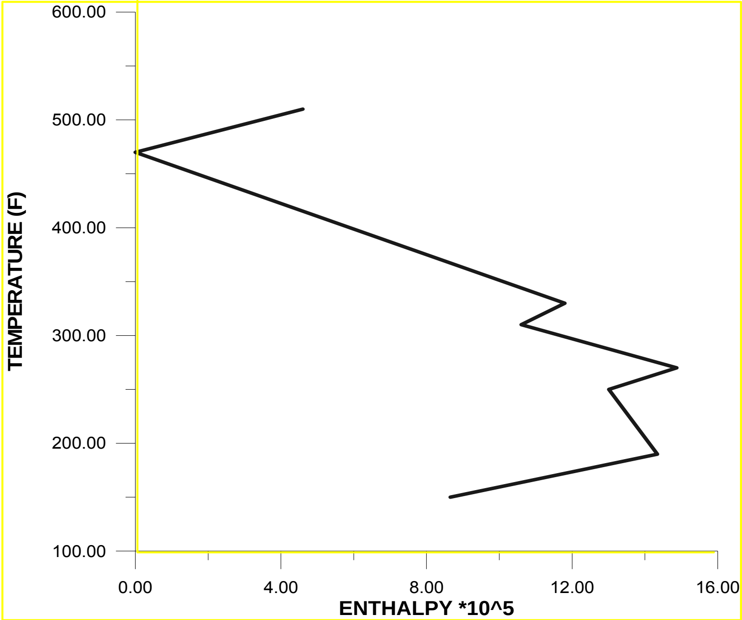


Figure (4.14): Grand Composite Curve for system A

The complete structure is the same as that obtained by TI method, which is given in figure (4.4), with the same area and cost.

4.3. Solving System C by pinch method with ΔT_{min}=10^{o} F:-

With this value of ΔT_{min} (5.5 ^{o}C), the temperature interval for system C which is given in table (3.3) was drawn, figure (4.5) and the cascade diagram figure (4.1). The calculations for this system are given in the tables and graphs below:

Table (4.10): The enthalpy values and cumulative H for hot streams

Temperature (^oF)	H	$H_{acc.}$
77	0	0
87	1.23×10^5	1.23×10^5
128	5.04×10^5	6.27×10^5
129	2.87×10^5	9.14×10^5
139	2.28×10^6	3.194×10^6
143	1.15×10^6	4.344×10^6
166	6.63×10^6	1.09×10^7
176	2.88×10^6	1.38×10^7
206	4.00×10^5	1.42×10^7
244	5.07×10^5	1.47×10^7

Table (4.11): the enthalpy values and cumulative H for cold streams

Temperature	H	$H_{Acc.}$
77	1.118×10^7	1.118×10^7
118	2.90×10^5	1.147×10^7
119	7.006×10^3	1.1485×10^7
129	7.006×10^4	1.1555×10^7
133	1.96×10^4	1.1575×10^7
156	0	1.1575×10^7
166	5.0×10^6	1.6575×10^7
196	1.5×10^7	3.1575×10^7
244	0	3.1575×10^7

Now, we can plot the hot composite curve figure (4.14) and the cold composite curve figure (4.15).

From these graphs we found that the pinch temperature is 156 °F for cold streams and 176 °F for hot streams.

Table (4.12): The enthalpy values for Grand Composite Curve

Mean Temperature	H	Acc.H $\times 10^5$
72	66.3+11.3+28.1+2.8+2.15+1.23	111.88
82	66.3+11.3+28.1+2.8+2.15	110.65
123	66.3+11.3+28.1+2.8	108.5
128.5	66.3+11.3+28.1	105.7
134	66.3+11.3	77.6
138	66.3	66.3
161	0	0
171	-21.2	21.2
201	21.2+146	167.2
239	21.2+146+5.07	172.24

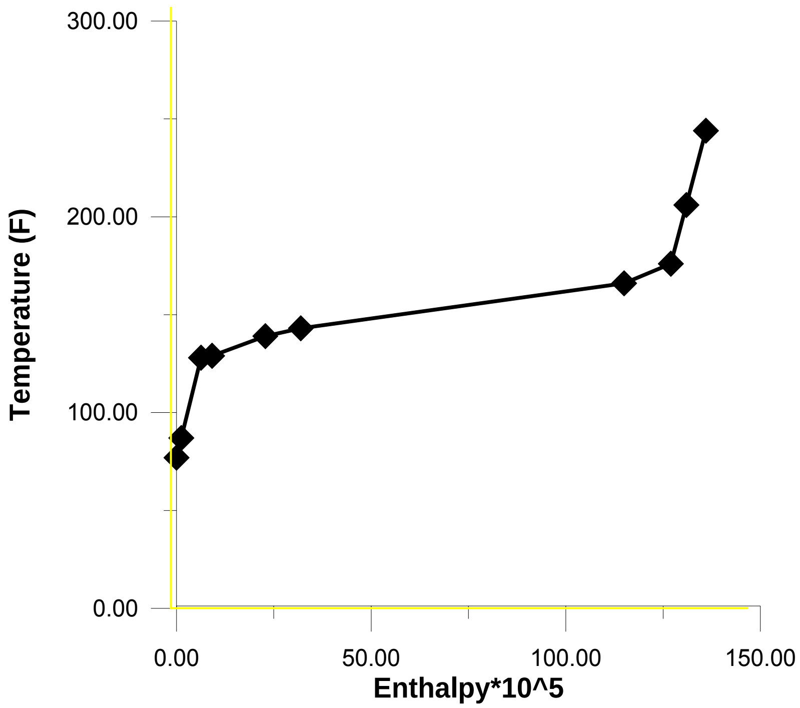


Figure (4.15): Hot Composite Curve of system C

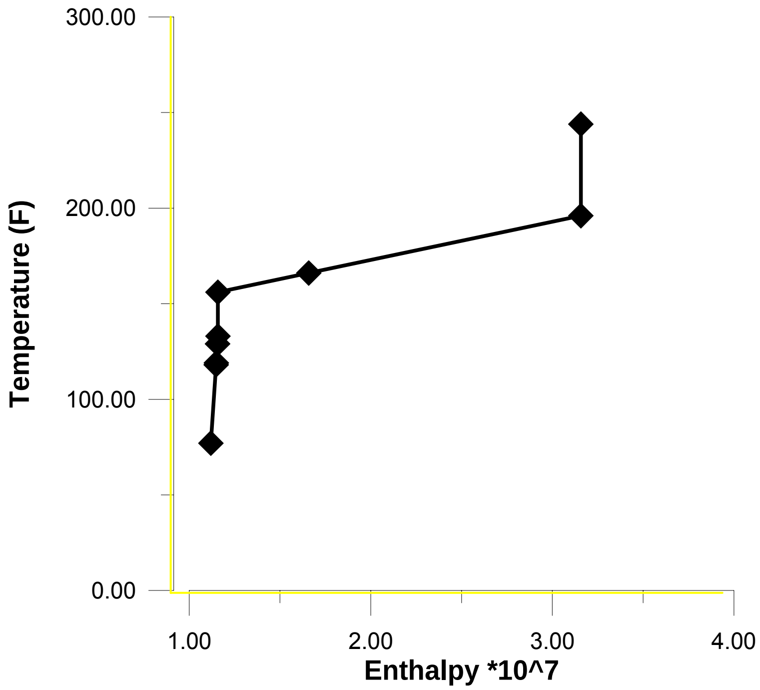


Figure (4.16): Cold Composite Curve of system C

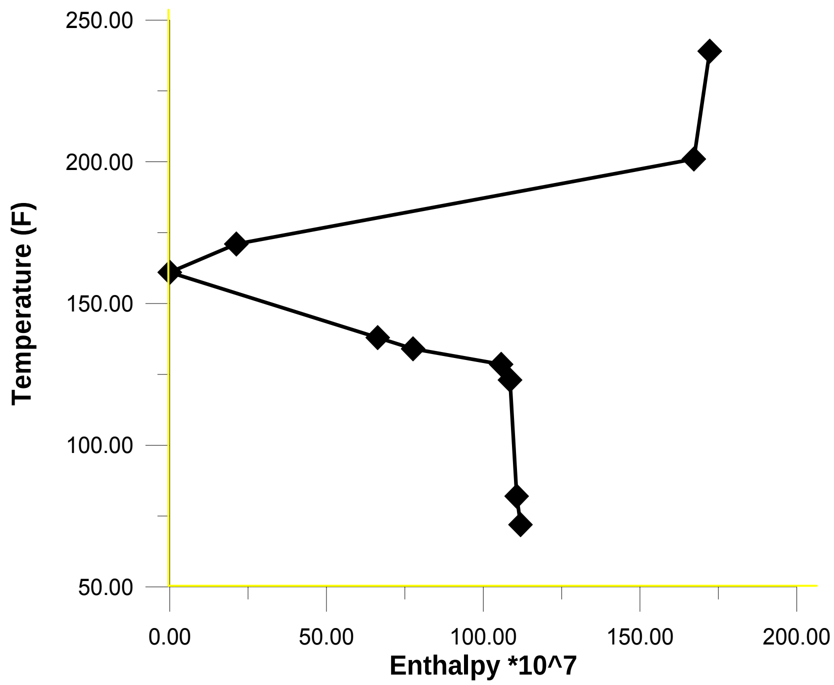


Figure (4.17): Grand Composite Curve for system C

After finding the curves concerned with system C, the networks above and below pinch must be found, then the complete structure will be found.

Figure (4.18): Design above the Pinch

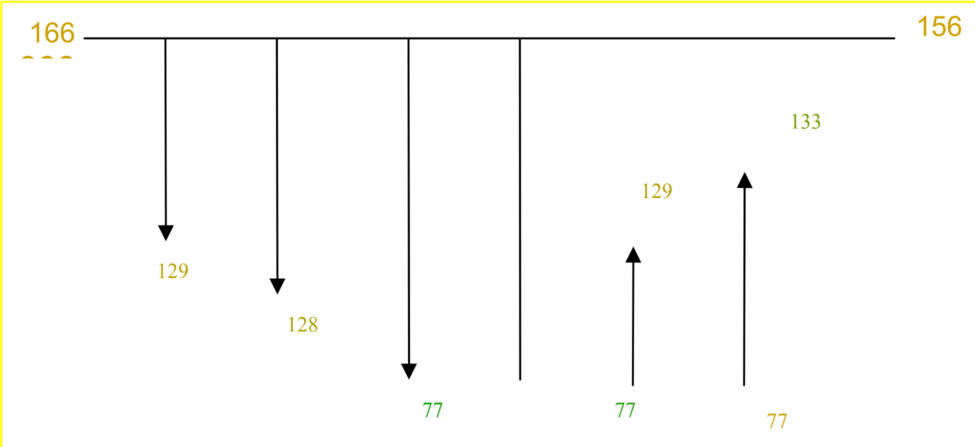


Figure (4.19): Design below the Pinch

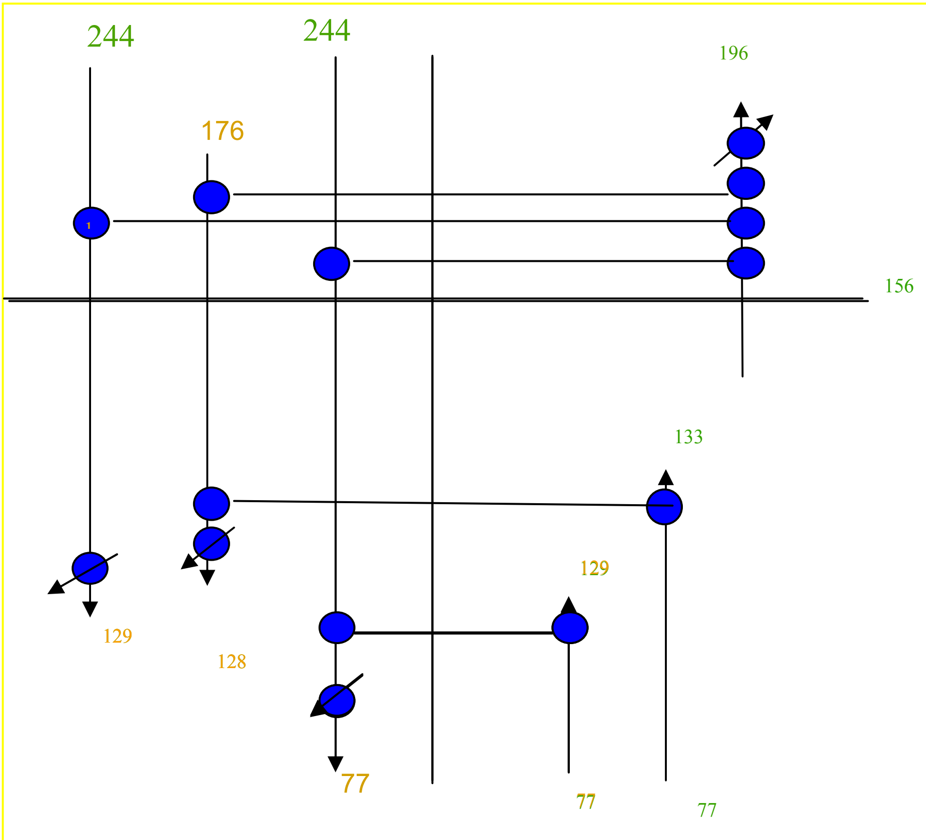


Figure (4.20): The complete structure for system C (ΔT_{min}=10^{o}F)

After we have done the calculations, we found that the area= 8763.2m^2 and its cost=1,015×10^6 ID/y.

Original number of heat exchangers=9

Reduced number of heat exchangers=7

4.4. General Discussion of the Heat Exchanger Network

The HEN synthesis problem is solved in different methods, some of these methods gives a single structure like Linnhoff Systematic method, TI method and pinch analysis. This structure may represent the optimum or nearly optimum and sometimes it's so far from the minimum structure cost. While the other methods which gives more than one structure, like Rudd and Ichikawa heuristics, gives a choice to select the minimum cost structure among many structures.

The HEN becomes very important in industry because it minimizes the energy conservation, maximize the heat recovery by using the heat available in any hot streams to heat the colder streams that reduce the using of external heating sources and cooling sinks. This leads to reduce the cost for these systems by recycling the same energy available in the same system.

4.5. Discussion of Results

4.5.1. Discussion of Heuristics Results with Comparison of Previous Works:-

Many workers were studied the HEN synthesis and introduced a different methods for networking, some of them take just one system and apply one heuristic on this system to find the minimum structure cost among the configurations that obtained by this heuristic. And some of them take more than one system and also apply one special heuristic or any method from the methods of networking.

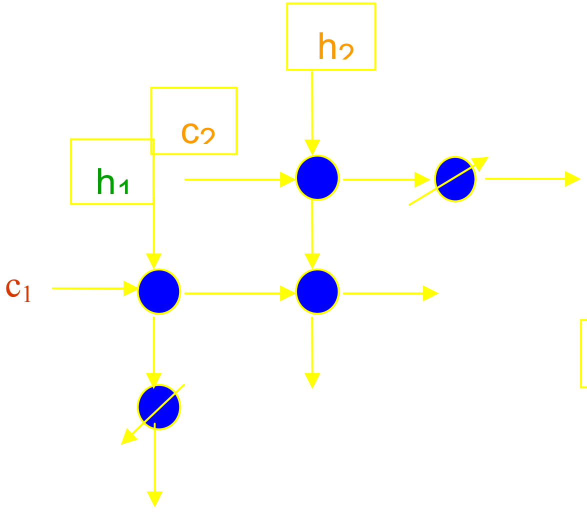
In this work, three systems were taken with four streams and six streams. These systems were chosen from literature because the design data for these systems are available, and to compare the results that obtained for these systems with the results obtained by these references.

Rathore and Powers [20] took system A and they applied Kobayashi heuristic to find 8 possibilities with its cost, and then chose the minimum cost to be the optimum. Kelahan and Gaddy [19] took three systems A, B and another system with five streams, and solved these systems by Kobayashi heuristic. Eight possibilities were obtained for system A and they gave just the minimum cost structure for system B and the five streams system without giving the all structures may obtained.

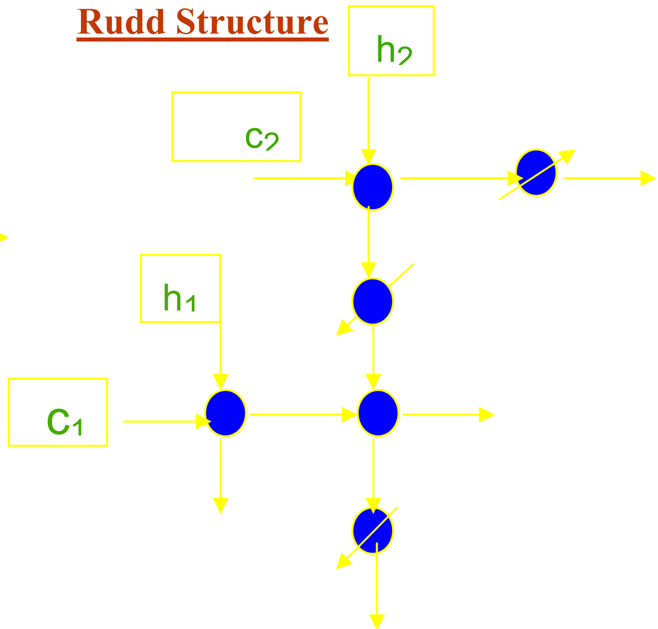
Linnhoff [10] chose four streams system to solve it by TI method and Linnhoff systematic method, where they both gave single structure.

In this work system A, B and C were chosen, solved first by heuristics method, Kobayashi used in the beginning for the networking of system A and B. System A gave the same 8 possibilities obtained by the first two workers, system B gave 25 possibilities, The Kobayashi heuristic covered all the possible networks because of its large possible matching. Therefore the minimum structure cost is certainly one of these structures in all cases. Then Rudd heuristic applied, for two systems to give 4 possibilities in system A and 5 possibilities for B. This heuristic gives a limited number of combinations in comparison with Kobayashi because these matching minimize the possibilities of networking matching. Sometimes Rudd and Kobayashi gives the same minimum structure cost as in system A (Appendix B1), where the minimum structure cost obtained by Kobayashi $=36.25\times10^6$ ID/y ($A=112.03\ m^2$) and the minimum structure cost obtained by Rudd= 36.25×10^6 ID/y ($A=112.03\ m^2$).

The structure of Kobayashi



Rudd Structure



And sometimes they do not give the same minimum structure cost as in system B (Appendix B2), where the minimum structure cost obtained by Kobayashi=58.17×10^{6} ID/y (A=237.50 m^2) and the minimum structure cost obtained by Rudd=107.61×10^{6} ID/y (A=662.06 m^2).

From these results, Rudd heuristic is the best for system A, because it gives the same minimum structure cost obtained by Kobayashi with little number of possibilities. While system B shows that, Kobayashi is the best heuristic, where its minimum structure cost has a cost less than that for that obtained by Rudd.

To compare the results of system A and B with the previous works, the costs of the minimum cost structures are given in table (4.13):-

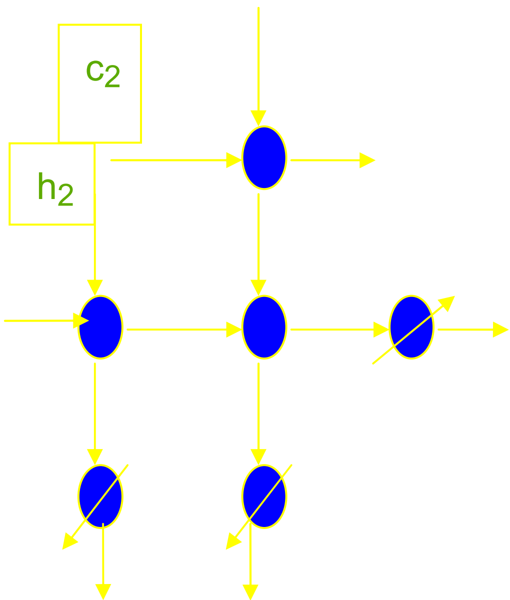
Table (4.13): comparison of costs in (ID/y) with previous works

System	This study	Rathore and powers	Pho and Lapiduse, Lee et al.
A	36.2×10^{6}	15.9×10^{6}	20.0×10^{6}
B	58.1×10^{6}	25.0×10^{6}	34.5×10^{6}

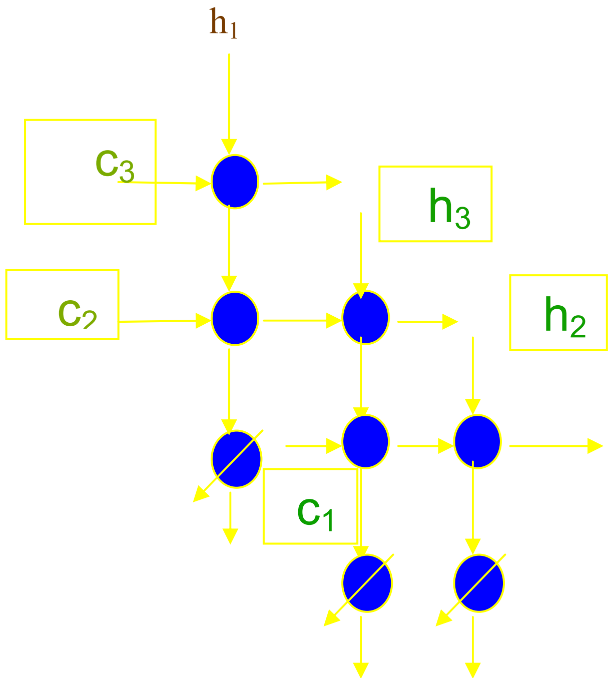
The big difference (40-50%) between the cost of these systems in this work and that of the past works is because of the correction to the cost of utilities (steam and cooling water).

Linnhoff systematic method is different from the previous two heuristics, which gives just one structure. If this structure cost have been compared with the minimum structure cost obtained by the previous heuristics, it is some times quite far from this minimum structure cost as in system A results (Appendix B1), where the single structure cost obtained by Linnhoff heuristic=113.6×10^6 ID/y (A=721.0 m^2) compared with the cost of the minimum structure cost obtained by the two heuristics is 36.25×10^6 ID /y (A=112.03 m^2), it's far enough to be the minimum. And in the second system (B), linnhoff structure cost is 60.8×10^6 ID/y (A=255.8 m^2) it's so close to that obtained by Kobayashi with cost=58.17×10^6 ID/y and so far from that obtained by Rudd which have a cost=107×10^6 ID/y. Appendix B2.

Linnhoff structure cost of system A



Linnhoff structure of system B



4.5.2. Discussion of Pinch Analysis Results:-

Two systems were chosen to be solved by pinch analysis "system A and C". System A when solved by this method it gives no sub network above the pinch, there is just a sub network below the pinch. Because of the pinch temperature is very high (480 ^{o}F for the hot streams and 460 ^{o}F for cold streams) compared with the temperatures of the streams that prevent the streams of lower temperature to pass through the pinch. For example the cold stream of 140 to 320 ^{o}F can not reach the pinch, also the hot stream of 320 to 200 ^{o}F. While the second hot stream is passed through one side of pinch 480 to 280 ^{o}F that lead to form just one sub network (below), because there is just one stream pass above the pinch. The three streams below can be matched to give the final structure.

System C, was also solved by pinch method, this system consists of six streams two of these streams never reached the pinch but the other streams will pass through it, that means two sub networks will be formed one above the pinch and one below the pinch. The pinch in this system would found to be (176 ^{o}F for hot streams and 156 ^{o}F for cold streams), which represented an intermediate temperature between the temperatures of streams that lead to form a complete structure of two sub networks, figure (4.2).

The number of exchangers required for the overall process is always less than or equal to that for minimum energy network. Using equation (3.4), the number of exchangers will be reduced. Reducing the number of exchangers will definitely lower the cost for equipment (Capital cost); however it will increase the cost of utilities (Operating cost). Therefore the main objective of this stage is to search for the lowest annual cost for the exchanger network. Where, in system A the original number of exchangers is 5. And after using equation (3.4) the number of exchangers will be 4. And in system C the number is reduced from 9 heat exchangers to 7.

4.5.3. Discussion of TI Method Results:-

TI method was applied on system A and C. In system A after finding the adjusted temperatures, and construct the cascade diagram the pinch temperature was found to be 460 ^{o}F for cold streams and 480 ^{o}F for hot streams. Which means it also gives one sub network because of the stream temperature is less than the pinch temperature. Therefore, there is only a sub network above the pinch, figure (4.9).

While, in system C the pinch temperature is 176 ^{o}F for hot streams and 156 ^{o}F for cold streams, most of the streams will pass through the pinch; it gives a complete structure with two sub networks, one above and another below the pinch, figure (4.2)

After the stage of finding the pinch temperature, the TI method and pinch analysis have the same procedure, where they have the same way of matching, according to its capacity flow rate.

The two methods aim to find the heat exchanger network for specified systems. Certainly, there is a similarity and difference between the two methods, where both of them give a single structure which may represent the minimum cost structure or not. The procedure is the same approximately, where both methods depending on finding the temperature interval diagram in order to find the heat duty for each interval to determine the pinch temperature. But the difference here is in TI method, where the temperature interval diagram will be found by adjusting the temperatures of hot streams by a ΔT_{min} which is equal to 20 ^{o}F in this work and then the temperatures will ranked in descending order to construct the temperature interval diagram. While in pinch analysis method there is no adjusted temperature, the temperature interval diagram was constructed by applying the temperatures of streams on the diagram.

In the pinch analysis there are graphs for the cold and hot curves and a graph for the grand composite curve to show the pinch temperature before find the final structure. In TI method there is no such graphs; the pinch temperature was found and then used it to find the final structure after matching the streams around the pinch.

4.6. Selection the Minimum Approach Temperature ΔT_{min}:-

The design of heat transfer equipment must always adhere to the second law of thermodynamics that prohibits any temperature cross over between the hot and the cold streams i.e. a minimum heat transfer driving force must always be allowed for a feasible heat transfer design. Thus the temperature of the hot and cold streams at any point in the exchanger must always have a minimum temperature driving force (ΔT_{min}). This ΔT_{min} value is very important in the heat recovery. The value of ΔT_{min} is depending on the overall heat transfer coefficients (U) and the geometry of the heat exchanger. In a network design, the type of the exchanger to be used will determine the practical value of ΔT_{min} for the network. For the case of a shell and tube heat exchanger, the value of ΔT_{min} value is 10 ^oC (at best) in this work (15-20) ^oF will be taken, which is equal to (8.3-11.1) ^oC. If smaller value for ΔT_{min} is chosen, the area requirements rise. If a higher value of a ΔT_{min} is selected the heat recovery in the exchanger decreases and demand for external utilities increases. Thus the selection of ΔT_{min} value has implications for both capital and energy costs. This means an increase in ΔT_{min} values result in higher energy costs and lower capital costs. And a decrease in ΔT_{min} values result in lower energy costs and higher capital costs. An optimum ΔT_{min} exists where the total annual cost of energy and capital costs is minimized.

The heat designed on the basis of the estimated optimum ΔT_{min} value is not always the most appropriate design. Avery small value, perhaps 8 ^oC, can lead to very complicated network design with a large total area due to low driving forces. The designer, in practice, selects a higher value (15 ^oC) and calculates the marginal increases in utility duties and area requirements. If the marginal cost increase is small, the higher value of ΔT_{min} is selected as the practical pinch point for the heat exchanger network.

4.6.1. The Effect of Changing ΔT_{min}:-

All the three systems are networked by ΔT_{min}=20 ^oF, and if this value will be changed, the cost of the network will affected directly. This affect had seen when system C was solved by pinch analysis again but with ΔT_{min}= 10^oF, the value of the cost will be $1{,}015\times10^6$ ID /y. While the cost for the same system before changing the ΔT_{min} =565.88×10^6ID/y. This means that the total cost for the network have been changed approximately by 45% after changing the parameter of ΔT_{min}. The number of exchangers will increase also with the decrease of ΔT_{min}; eight heat exchangers were used in case of 20 ^oF and nine heat exchangers in case of 10 ^oF.

When a small value of ΔT_{min} is chosen ($\Delta T_{min} \leq 10^o C$), the area requirements in the heat exchanger will raise, if higher value of ΔT_{min} is chosen ($\Delta T_{min} \geq 10^oC$) the heat recovery will decrease and demand for external utilities increases. This means an increase in ΔT_{min} values gives higher energy costs and lower capital costs. And a decrease in ΔT_{min} values gives lower energy costs and higher capital costs. An optimum ΔT_{min} exists when the total annual cost of energy and capital cost is minimized, where the optimum is 10^o C for ΔT_{min}, in our case of shell and tube heat exchangers a value of 8.3-11.1^o C is reasonable, as in most references 11.1^{o}C was chose for this work.

Chapter Five
COCLUSIONS AND SUGGESTIOANS

5.1. Conclusions:-

1. Three methods were used for this work; Heuristics method, TI and pinch analysis methods which applied on three liquid systems to find the minimum cost configuration for the heat exchanger network.

2. The log mean temperature difference is selected to be 11^{o}C (20 ^{o}F); this is the more appropriate value for the shell and tube heat exchanger. Decreasing the log mean temperature difference from 20F^{o} to 10F^{o} lead to raise the area requirements, that means a lower energy costs and higher capital costs.

3. Increasing the number of streams lead to increase the number of the possibilities; also the number of exchangers will increase with increasing the number of streams, and also reducing the number of exchangers will definitely lower the cost for equipment (Capital Cost). However it will increases the cost of utilities (Operating cost).

5.2. Suggestions and future work:-

1. This work can be extended by using two phase flow instead of single phase that means the heat capacity of the streams will be change.

2. Stream splitting can be considered for future work, it will be used if unequal number of hot and cold streams system is taken.

3. A special method for optimization can be used to determine the optimum configuration.

4. Develop a computer program to give the configurations directly for any number of hot and cold streams as figures after taking the basic design data as input data. And then the calculations of area and cost are done by this program.

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Appendix A

Cost Calculations

The cost of utilities can be corrected by

$$C_s=24*365*C_{s1}*m_w \qquad \ldots\ldots A_1$$

$m_{w=} Q/\lambda$

Where C_s for 1000 lb (453.6 kG) of steam= 4059.15 ID

For 1 lb of steam $=2.7*10^{-3}$ $

λ= 656.6 Btu/lb

At saturated pressure 6.636 KN/m^2 (962.lb/in^2.abs)

Temperature= 280C^o (540^o F)

$$C_W= 24*365*C_{w1}*m_w \qquad \ldots\ldots A_2$$

$m_w= Q/(Cp.\Delta T_{w)}$

Where C_W= for 4546 liter (1000 gal) of cooling water =124 ID

For 1 lb of cooling water $5*10^{-5}$ $

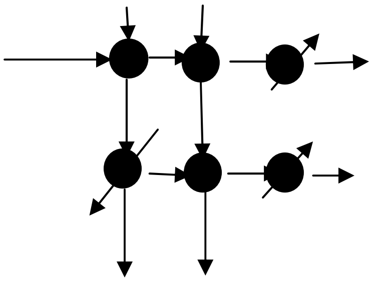
System A

Heat exchangers network optimization

stream	m(lb/hr)	cp(Btu/lb.F) Tin		Tout
A	20643	0.7	140	320
B	27778	0.6	320	200
C	23060	0.5	240	500
D	25000	0.8	480	280

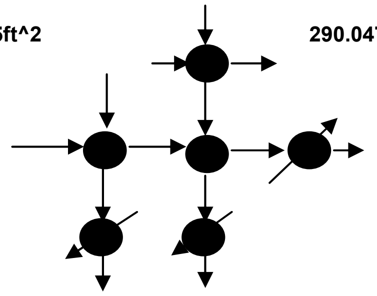
t1= Input temperature of hot streams.
t2= Input temperature of cold stream.
t3= Output temperature of cold stream.
t4= Output temperature of hot streams.
t3=t1-20

First possibilty



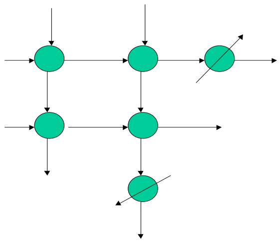
heat exchanger {1}		t1=	320	t2=	240
Q©=	691800	t3=	300		
ΔTlm=	28.2443496	t4=	278.49233		
		A=	163.2893		
C=350(A)^0.6		C=	7444.6224		
heat exchanger {2}		t1=	480	t2=	300
Q©=	1844800	t3=	460		
		t4=	387.76		
ΔTlm=	45.8186573	A=	268.42049		
		C=	10031.305		
heat exchanger {3}		t1=	387.76	t2=	140
				t4=	280
Q(h)=	2155200	t3=	288.09		
ΔTlm=	118.695255	A=	121.04949		
		C=	6220.794		
Ctotal=∑ C(E)i		Ctotal=	23696.722		
heaters					
heater {1}					
the cost for 1 lb of steam=		2.7*10^-3	$		
Q=	461200	Ts=	540	λ=	656.6
		Tin=	460	Tout=	500
ΔTlm=	57.7078016				
			A=	39.95993496	
C=350*(A)^0.6			C=	3199.211174	
			Cs=	16613.31465	
heater {2}		Ts=	540		
		Tin=	288.09	Tout=	320
Q=	461102.691				
ΔTlm=	235.594941		A=	9.785920891	
ms=	702.258134		C=	1375.400142	
			Cs=	16609.80939	

Ch total =	4574.61132			Cstotal	33223.12404	
cooler			the cost of one lb of cooling water =5*10^-5 lb/hr			
			Twin=	100	Twout=	180
			Tin=	278.4923	Tout=	200
Q=	1308215.47					
ΔTlm=	99.2442413		A=	87.878514		
			C=	5133.3121	Cw=	7162.477
J=	43726.0656	$/YR	65589098	ID		
A=	3122.15ft^2		290.04774	m^2		
second possibility						



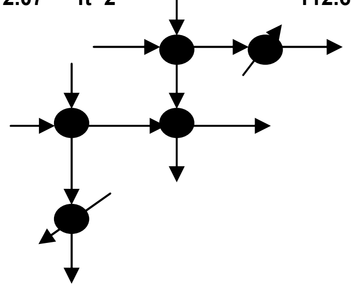
heat exchanger {1}				C=	7444.622	
heat exchanger {2}			t1=	480	t2=	140
				t3=	320	
Q=	2601018			t4=	349.9491	
ΔTlm=	183.845044			A=	94.31921365	
				C=	5355.846816	
heat exchanger {3}			t1=	349.9491	t2=	300
				t3=	329.9491	
Q=	345313.123			t4=	332.6834439	
∆Tlm=	25.8246886			A=	89.14289441	
				C=	5177.499708	
Ctotal =	17977.9685					
Heaters						
heater {1}			Ts=	540	λ=	656.6
			Tin=	329.9491	Tout=	500
Q=	1960686.88					
ΔTlm=	102.53478			A=	95.61082018	
				C=	5399.73281	
				Cs=	69743.982	
Coolers						
cooler {1}			Twin=	100	Twout=	180
Q=	1308215.47		Tin=	278.4923	Tout=	200
ΔTlm=	99.2442413			A=	87.87851391	
				C=	5133.312065	
mw=	16352.6933			Cw=	7162.479674	
cooler {2}			Twin=	100	Twout=	180
			Tin=	332.6834	Twout=	280
Q=	1053668					
ΔTlm=	165.967198			A=	42.32434725	
				C=	3311.480528	
m(w)=	13170.85			Cw=	5768.8323	
Cc total =	8444.79259					
Cw total =	12931.312					
J=	75512.8143	$/YR	113269221	ID		
A=	7761.058 ft^2		721.00229	m^2		

third possibilty



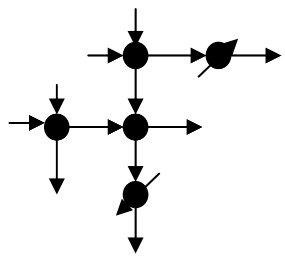
heat exchanger {1}			C=	7444.622		
heat exchanger {2}			C=	10031.31		
heat exchanger {3}			t1=	278.4923	t2=	140
					t4=	200
Q=	1308215.47		t3=	230.53332		
ΔTlm=	53.7549158				A=	162.24444
					C=	7416.0038
					C=	7416.0038
heat exchanger {4}			t1=	387.76	t2=	230.5333
			t3=	320		
Q=	1292802.76		t4=	323.11986		
ΔTlm=	79.5284811				A=	108.37231
					C=	5821.2874
C total =∑ C(E)i					C total=	30713.223
heater			C=	3346.684		
			Cs=	16405.44		
cooler		Tin=	323.1199	Tout=	280	
		Twin=	100	Twout=	180	
Q=	862398					
ΔTlm=	160.855929				A=	26.806534
					C=	2517.7491
mw=	10779.975				Cw=	4721.6291
J=	24784.8347	$/YR	37177252	ID		
A=	1212.07	ft^2	112.6013	m^2		

fourth possibility



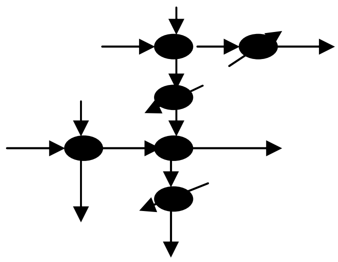
heat exchanger [1]		t1=	480	t2=	240
		t3=	460		
Q=	2536600			t4=	353.17
ΔTlm=	53.7573348			A=	314.57413
				C=	11033.209
heat exchanger [2]		t1=	353.17	t2=	?

			t3=	320	t4=	280
Q=	1460000					
					t2=	218.9
ΔTlm=	45.5				A=	213.919
					C=	8754.2241
heat exchanger [3]			t1=	320	t2=	140
			t3=	218.7273		
Q=	1127107.8				t4=	320
ΔTlm=	105.9213				A=	70.939
					C=	4514.3901
C total=∑ C(E)i					Ctotal=	24301.823
heater					C=	3346.684
					Cs=	16405.44
cooler			Tin=	251.7435	Tout=	200
			Twin=	100	Twout=	180
Q=	850006.8					
m(w)=	10625.055					
ΔTlm=	84.67				A=	66.927
					C=	4359.4215
J=	24170.0129	$/YR	36255019		Cw=	4563.78
A=	1205.98	ft^2	112.03554	m^2		
fifth possibility						



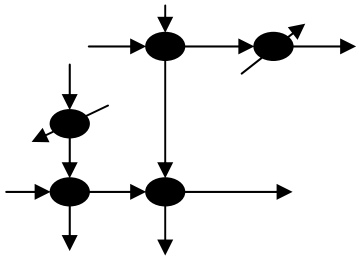
heat exchanger [1]						
			t1=	320	t2=	140
Q=	2000016		t4=	200	t3=	140
ΔTlm=	50.4				A=	264.55238
					C=	9944.319
heat exchanger [2]					C=	11033.21
heat exchanger [3]			t1=	353.17	t2=	278.4085
			t3=	320		
Q=	606904.5				t4=	322.82478
ΔTlm=	38.69				A=	104.5756
					C=	5698.0501
C total=∑ C(E)i					C total=	26675.579

heater					cost=	3346.684
					Cs=	16405.44
cooler			323.1199	Tout=	280	
			100	Twout=	180	
Q=	862398			m(w)	10750	
ΔTlm=	160.79				A=	35.756701
					C=	2992.8332
					Cw=	4721.6312
J=	24428.5809	$/YR	36642871	ID		
A=	1183.17	ft^2	109.91649	m^2		
sixth possibility						



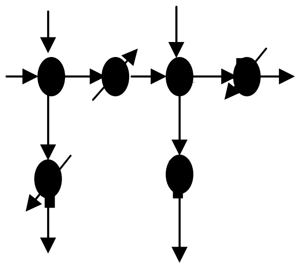
heat exchanger [1]					C=	9963.918
heat exchanger [2]					C=	11033.21
heat exchanger [3]			t1=	333	t2=	278.4085
			t3=	320		
Q=	601001.3				t4=	340
ΔTlm=	31.23701				A=	128.26693
					C=	6440.7562
C total =∑ C(E)i					C total=	27437.884
heater					cost=	3346.684
					Cs=	16405.44
cooler		Tin=	353.17	Tout=	333	
		Twin=	100	Twout=	180	
Q=	403400			m(w)=	5042.5	
ΔTlm=	189.487663				A=	14.192657
					C=	1719.1203
					Cw=	2208.615
cooler		Tin=	309.9499	Tout=	280	
		Twin=	100	Twout=	180	
Q=	598998			m(w)=	7487.475	
ΔTlm=	153.618455				A=	25.995054
					C=	2471.7382
					Cw=	2208.615
C=∑ C©i					C=	4190.8585
J=	25391.1117	$/YR	38086668	ID	Cw=	3279.5141
A=	1261.81	ft^2	117.22215	m^2		

seventh possibility



heat exchanger [1]				C=	11033.21	
heat exchanger [2]				C=	8732.754	
heat exchanger [3]			t1=	?	t2=	140
			t3=	218.7273	t4=	200
Q=	1137617.36				t2=	268.2565
ΔTlm=	54.5973573				A=	138.90994
					C=	6756.2863
∑ C(E)i=					Ct=	26522.25
heater					cost=	3346.684
					Cs=	16405.44
cooler		Tin=	320	Tout=	268..2565	
		Twin=	100	Twout=	180	
Q=	862398.566			m(w)=	10779.98207	
ΔTlm=	153.695587				A=	37.407214
					C=	3074.9727
					Cw=	4721.6321
J=	24421.4628	$/YR	36632194	ID		
A=	1182.603	ft^2	109.86382	m^2		

eighth possibility



heat exchanger [1]					C=	7444.622
heat exchanger [2]			t1=	?	t2=	140
			t3=	320	t4=	280
Q=	2601018		t1=	410.0509		
ΔTlm=	113.194641				A=	153.18852
					C=	7164.7952
heat exchanger [3]			t1=	480	t2=	?
			t3=	460	t4=	410.0509
Q=	1398982				t2=	338.66592
ΔTlm=	40.3857207				A=	230.93674
					C=	9165.6625
C total=∑C(E)i					C total=	23775.08
heater [1]					cost=	3346.684
					Cs=	16405.44
heater [2]			Tin=	300	Tout=	338.6659
			Ts=	540	λ=	656.6

Q=	445817.827					m(s)=	678.97933
ΔTlm=	220.101294					A=	10.12756
C(h)=∑C(H)i						Cs=	15858.27
C(h)=	1404.01241						
cooler						C=	5566.29
						Cw=	7206.611
J=	42879.5276	$/YR	64319291	ID			
A=	3022.06	ft^2	280.74937	m^2			

optimization

the costs values		Areas (m^2)
J1=	65589098.34	290.04774
J2=	113269221.5	721.00229
J3=	37177252.02	112.6
J4=	36255019	112.0355
J5=	36642871.31	112.0456
J6=	38086667.59	117.222
J7=	36632194.27	112.564
J8=	64321627.97	280.74937
min.=	36255019	112.0355

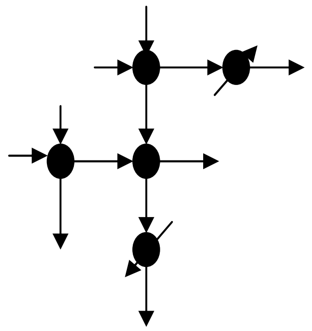
The fourth structer is the optimum

Rudd,Lee,and Masso heuristic

stream		cp(Btu/lb.F) Tin	Tin	Tout
A	20643	0.7	140	320
B	27778	0.6	320	200
C	23060	0.5	240	500
D	25000	0.8	480	280

matching the highest supply temp.hot stream with
the highest target temperature cold stream.

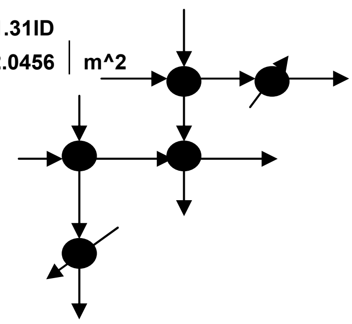
1st possibility



J= 36642871.31ID

A= 112.0456 m^2

2nd possibility

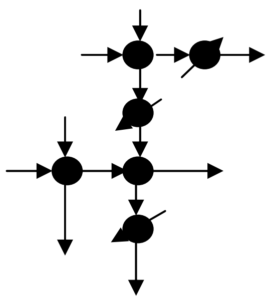


3rd possibility

36255019.29ID ID

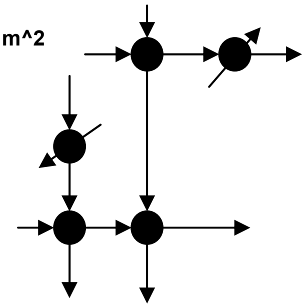
A= 112.0355 m^2

B1-7



J=	38086667.59ID	
A=	117.222	m^2

4th possibility



J=	36632194.27ID	
A=	112.564	m^2

Optimization

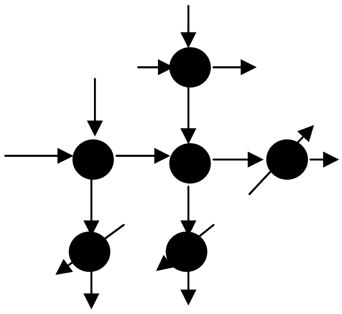
Cost (ID/YR)		Area (m^2)
36642871.31ID		112.0456
36255019.29ID		112.0355
38086667.59ID		117.222
36632194.27ID		112.564

min.=	36255019.29ID		112.0355

THE SECOND STRUCTURE IS THE OPTIMUM.

Linhoff heuristic

stream	m(lb/hr)	cp(Btu/lb.F) Tin	Tin	Tout	m.Cp
A	20643	0.7	140	320	14450.1
B	27778	0.6	320	200	16666.8
C	23060	0.5	240	500	11530
D	25000	0.8	480	280	20000



J=	113269221.5ID	
A=	721.002288	m^2

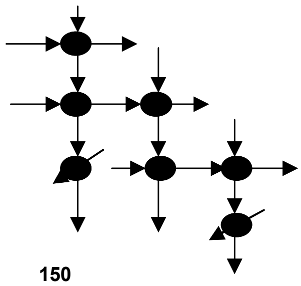
this structure is not represent the optimum ,which is quite far from the optimum .

Appendix B2

System B

Stream	m(lb/hr)	cp	Tin	Tout
1	20000	0.8	100	430
2	40000	0.7	440	150
3	36000	0.91	180	350
4	35000	0.68	520	300
5	31000	0.85	200	400
6	42000	0.8	390	150

1st possibility



U= 150

heart exchanger [1] t1= 440 t2= 200
t3= 400

Q= 5270000
t4= 251.7857143
ΔTlm= 45.63951504
A= 769.800759 C= 18875.35139

heat exchanger [2] t1= 251.78571 t2= 100
Q= 2108571.2 t3= 231.7857
t4= 176.4796
ΔTlm= 42.1083744
A= 333.832439 C= 11433.65716

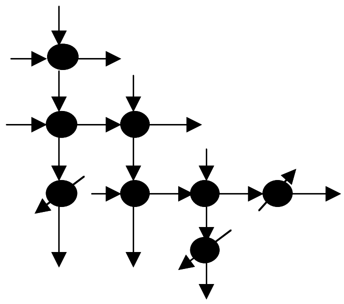
heat exchanger [3] t2= 231.7857 t1= 520
Q= 3171428.8 t3= 430
t4= 386.746689
ΔTlm= 119.553414
A= 176.84864 C= 7809.605194

heat exchanger [4] t1= 386.74669 t2= 180
Q= 2064571.2 t4= 300
t4= 243.021099
ΔTlm= 131.506286
A= 104.662738 C= 5700.898392

heat exchanger [5]
Q= 3504628.8 t1= 390 t2= 243.0211
t4= 285.695571 t3= 350
ΔTlm= 41.3228126
A= 565.406624 C= 15685.00205

COOLERS
U= 150

cooler [1]					
Tin=	176.4796		Tout=	150	
Twin=	100		Twout=	156.4796	
Q=	756000				
ΔTlm=	32.7407				
A=	153.936843		C=	7185.774589	
cp for water =1					
m(w)=	13385.3639		Cw=13385.364*24*365*5*10^-5		
Cw=	5862.7894	$/ yr			
cooler [2]					
Tin=	285.6956		Tout=	150	
Twin=	100		Twout=	180	
Q=	4559372.16				
ΔTlm=	74.4056172				
m(w)=	56992.152				
Cw=	24962.5626				
A=	408.51505		C=	12906.03625	
total cost of heat exchangers=			59504.5142		
total cost of coolers=			20091.81084		
total cost of cooling water=			30825.35197		
the total cost of the structure=J					
J=δ*{Ch.ex +Cc+Ch}+U					
J=	38784.9845	$/YR	58177476.71	ID/YR	
A=	2556.57	ft^2	237.505353	m^2	
second possibility					

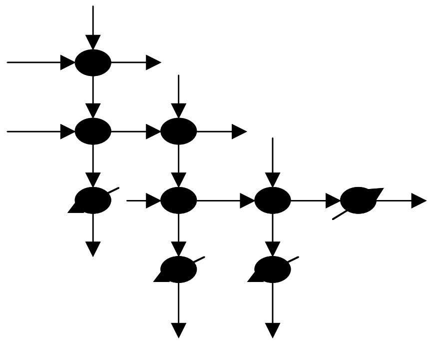


heat exchanger [1]					
Q=	5569200	t1=	440	t2=	180
t4=	241.1			t3=	350
ΔTlm=	74.6195813				
A=	497.563767	C=	14527.04537		
heat exchanger [2]					
Q=	1937600	t1=	241.1	t2=	100
t4=	171.9			t3=	221.1
ΔTlm=	40.5613253				
A=	318.464282	C=	11114.87244		
heat exchanger [3]					
Q=	3342400	t1=	520	t2=	221.1
t4=	379.563025			t3=	430
ΔTlm=	121.02107				

A=	184.122208	C=	8000.769324		
heat exchanger [4]					
Q=	4204485.05	t1=	379.56303	t2=	200
t4=	202.903989			t3=	359.563
∆Tlm=	8.8596652				
A=	3163.76519	C=	44074.82435		
heat exchanger [5]		t1=	390	t2=	359.563
Q=	275014.95			t3=	370
T4=	381.815031				
∆Tlm=	20				
A=	91.67165	C=	5265.129692		
		Ctotal=	82982.64		
Coolers					
cooler [1]					
Tin=	171.9	Tout=	150		
Twin=	100	Twout=	151.9		
Q=	613200	m(w)=	11815.0289		
∆Tlm=	32.7407	A=	124.8598837		
		C=	6337.555857		
		C(w)=	5174.982659		
Heaters					
heater [1]					
Tin=	370	Tout=	400		
Tsin=	456.3	Tsout=	456.3		
Q=	790500				
m(s)=	1030.10164				
∆Tlm=	70.2353953	A=	56.27504454		
		C=	3928.778575		
heater [2]		Cs=	28119.03		
Tin=	202.904	Tout=	300		
Tsin=	456.3	Tsout=	456.3		
Q=	2310884.8				
m(s)=	3011.31717				
∆Tlm=	200.953588	A=	57.49797316	C=	3979.784588
				Cs=	71223.67382

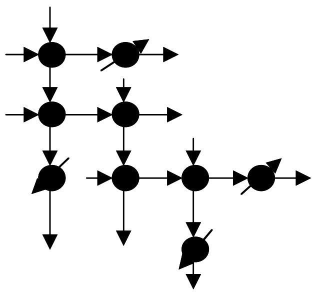
total cost of heat exchangers=		82982.64	
total cost of coolers=		6337.5559	
total cost of heaters=		7908.563163	
total cost of cooling water=		5174.9827	
total cost of steam=		99342.70382	
J= 105308.543	$/YR	157962814.3	ID/YR
A= 15473.449	FT^2	1437.483412	M^2

3rd possibility



heat exchanger [1]		t1=	440	t2=	200
Q=	5270000			t3=	400
t4=	251.785714				
ΔTlm=	45.639515				
A=	769.800759	C=	18875.35139		
heat exchanger [2]		t1=	251.78571	t2=	180
Q=	1696499.86			t3=	231.78571
t4=	191.196418				
ΔTlm=	15.1749693				
A=	745.306221				
C=	18512.6629				
heat exchanger [3]		t1=	520	t2=	231.7857
Q=	3872700.47			t3=	350
t4=	357.281493				
ΔTlm=	146.623938				
A=	176.083138	C=	7789.304924		
heat exchanger [4]					
Q=	3796503.84	t1=	357.28149	t2=	100
t4=	197.764522			t3=	337.28149
ΔTlm=	49.0062247				
A=	516.465525		C=	14855.69063	
heat exchanger [5]		t1=	390	t2=	337.2815
Q=	523496			t3=	370
t4=	374.419762				
ΔTlm=	27.6907952				
A=	126.033698		C=	6373.236762	
Coolers					
cooler [1]					
Tin=	191.19642	Tout=	150		
Twin=	100	Twout=	171.19462		
Q=	1153499.76	m(w)=	16202.06358		
ΔTlm=	32.7419514	A=	234.8668318		
		C=	9258.935485		
cooler [2]		C(w)=	7096.503849		
Tin=	374.41976	Tout=	150		
Twin=	100	Twout=	180		

Q=	7540503.94		m(w)=	94256.2992		
∆Tlm=	106.347665		A=	472.6951566		
			C=	14086.9423		
Heaters			Cw=	41284.25905		
heater [1]						
Tin=	197.76452		Tout=	300		
Tsin=	536		Tsout=	536		
Q=	2433204.42		m(s)=	3170.712046		
∆Tlm=	284.058037		A=	42.82935358		
			C=	3335.131453		
heater [2]			C(s)=	74993.68131		
Tin=	370		Tout=	430		
Tsin=	456.3		Tsout=	456.3		
Q=	960000		m(s)=	1250.977326		
∆Tlm=	50.4939716		A=	95.06085271		
			C=	5381.07528		
			C(s)=	29588.11572		
J=	162809.393	$/yr		244214089.5	ID	
A=	27399.42	ft^2		2545.406118	m^2	
4th possibility						



heat exchanger [1]						
Q=	4800000		t1=	440	t2=	100
t4=	268.571429				t3=	400
∆Tlm=	89.3800528					
A=	358.021717		C=	11923.77211		
heat exchanger [2]						
Q=	2246400.05		t1=	268.57143	t2=	180
t4=	188.342857				t3=	248.5714
∆Tlm=	13.3327107					
A=	1123.25248			C=	23678.51572	
heat exchanger [3]						
Q=	3322799.95		t1=	520	t2=	248.5714
t4=	380.386557				t3=	350
∆Tlm=	150.099702					
A=	147.581903			C=	7006.286764	
heat exchanger [4]						
Q=	1913200.13	t1=	380.38656	t2=	200	
t3=	272.6			t4=	300	
∆Tlm=	103.84					
A=	122.82			C=	6275.94	

heat exchanger [5]

Q=	9749500	t1=	390	t2=	272.60721
t4=	99.8363095			t3=	370
∆Tlm=	49.6556326				
A=	1308.94852	C=	25955.0329		

Coolers

cooler [1]

Tin=	188.34286	Tout=	150
Twin=	100	Twout=	168.34286
Q=	1073600.08		
m(w)=	15709.0217		
∆Tlm=	32.7407		
A=	218.606623	C=	8868.823938
		C(w)=	6880.55151

cooler [2]

Tin=	313.62203	Tout=	150
Twin=	100	Twout=	180
Q=	5497700.21		
m(w)=	68721.2526		
∆Tlm=	85.0688697		
A=	430.843091	C=	13324.76394
Heaters		C(w)=	30099.90864

heater [1]

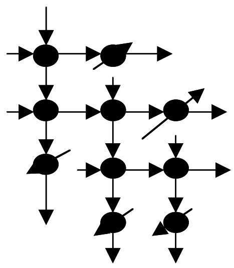
Tin=	400	Tout=	430
Tsin=	456.3	Tsout=	456.3
Q=	480000		
m(s)=	625.488663		
∆Tlm=	39.4153083	C=	4119.038325
A=	60.8900477	Cs=	14794.05786

heater [2]

Tin=	370	Tout=	400
Tsin=	456.3	Tsout=	456.3
Q=	790500		
m(s)=	1030.10164		
∆Tlm=	70.2353953		
A=	56.2750445	C=	3928.778575
		c(s)=	24363.96403

total cost of heat exchangers =			64888.12	
total cost of coolers =			22193.58	
total cost of heaters=			8047.81	
total cost of cooling water =			36980.46	
total cost of steam=			24363.964	
J=	70857.375	$/YR	106286062.5	ID
A=	6980.101	ft^2	648.4513829	m^2

5th possibility



heat exchanger [1]

Q=	4800000	t1=	440	t2=	100
t4=	268.571429			t3=	400
ΔTlm=	89.3800528				
A=	358.021717	C=	11923.77211		

heat exchanger [2]

Q=	2246400.05	t1=	268.57143	t2=	180
t4=	188.342855			t3=	248.5714
ΔTlm=	13.3327212				
A=	1123.2516	C=	23678.50458		

heat exchanger [3]

Q=	3977999.95	t1=	390	t2=	248.5714
t4=	271.607144			t3=	370
ΔTlm=	21.4821201				
A=	1234.51501	C=	25059.12309		

heat exchanger [4]

Q=	1359848.14	t1=	271.60714	t2=	200
t4=	231.135469			t3=	251.6071
ΔTlm=	25.1583653				
A=	360.343534	C=	11970.10844		

heat exchanger [5]

Q=	3910151.86	t1=	520	t2=	251.6071
t4=	355.707905			t3=	400
ΔTlm=	111.862129				
A=	233.033996	C=	9215.515081		

Coolers

cooler [1]

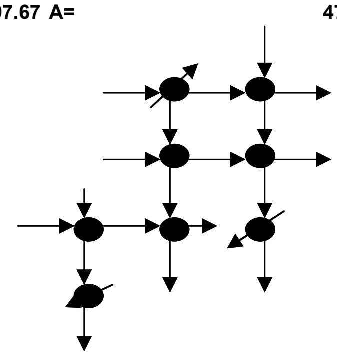
Tin=	370	Tout=	350
Twin=	100	Twout=	180
Q=	655200		
m(w)=	8190		
ΔTlm=	218.629535		
A=	19.9790024	C=	2110.631052
		C(w)=	3587.22

cooler [2]

Tin=	355.70791	Tout=	300
Twin=	100	Twout=	180
Q=	1325848.26		
m(w)=	16573.1032		
ΔTlm=	187.591888		
A=	47.1181803	C=	3531.67841

cooler [3]			Cw=	7259.019213	
Tin=	188.34286	Tout=	150		
Twin=	100	twout=	168.34286		
Q=	1073600.08				
m(w)=	15709.0217				
ΔTlm=	32.7407	A=	218.6066229		
			C=	8868.823938	
			C(w)=	6880.55151	
cooler [4]					
Tin=	231.13547		Tout=	150	
Twin=	100		Twout=	180	
Q=	2726151.79				
m(w)=	34076.8974				
ΔTlm=	50.5656102		A=	359.421061	
			C=	11951.71305	
Heaters			C(w)=	14925.68106	
heater [1]					
Tin=	400		Tout=	430	
Tsin=	456.3		Tsout=	456.3	
Q=	480000				
m(s)=	625.488663				
ΔTlm=	39.4153083		A=	60.89004768	
			C=	4119.038325	
			C(s)=	14794.05786	
total cost of heat exchangers =				81754.80962	
total cost of coolers =				26462.84645	
total cost of heaters=				4119.038325	
total cost of cooling water=				32652.47178	
total cost of steam=				14794.05786	
$/yr	58680.1991	J=		88020298.62	ID
ft^2	5097.67	A=		473.573543	m^2

6th possibility

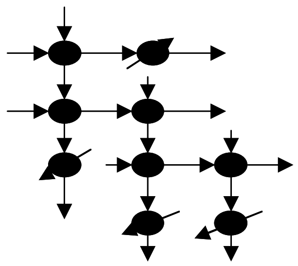


heat exchanger [1]					
t1=	390	t2=	200		
t3=	370				
Q=	4479500	t4=	256.6815476		
ΔTlm=	35.212603	A=	848.0865031	C=	20004.70426

heat exchanger [2]					
t1=	256.6815	t2=	100		
t3=	236.6815				
Q=	2186904	t4=	191.5950714		
∆Tlm=	47.0510943	A=	309.8622935	C=	10933.75361
heat exchanger [3]					
t1=					
t3=					
Q=					
∆Tlm=					
heat exchanger [4]					
t1=	520	t2=	236.6815		
t4=	430				
Q=	3093096	t4=	390.0379832		
∆Tlm=	118.877624	A=	173.461071	C=	7719.501544
heat exchanger [5]					
t1=	390.038	t2=	180		
t3=	300				
Q=	2142904.4	t3=	245.4122222		
∆Tlm=	131.930062	A=	108.2848682	C=	5818.46877
Coolers					
cooler [1]	440	t2=	245.4122		
Tin=	350				
Twin=	3426296.33	t4=	317.632274		
Q=	80.7841989	A=	282.7530115	C=	10349.33364
∆Tlm=					
	191.5951	Tout=	150		
	100	Twout=	171.5951		
	1397595.36	m(w)=	19520.82419		
	32.7407	A=	284.5785945	C=	10389.37405
cooler [2]				C(w)=	8550.120995
Tin=	317.6323	Tout=	150		
Twin=	100	Twout=	180		
Q=	4693704.4	m(w)=	58671.305		
∆Tlm=	86.5450663	A=	361.5614848	C=	11994.36722
Heaters				C(w)=	25698.03159
heater [1]					
Tin=	370	Tout=	400		
Tsin	456.3	Tsout=	456.3		
Q=	790500	m(s)=	1030.101642		
∆Tlm=	70.2353953	A=	56.27504454	C=	3928.778575
				C(s)=	24363.96403

total cost of heat exchangers=			54825.76182	
total cost of coolers=			22383.74127	
total cost of heaters=			3928.778575	
total cost of cooling water=			34248.15259	
total cost of steam=			24363.96403	
J=	66725.9448	$/YR	100088917.2	ID/YR
A=	6315.06	ft^2	586.669074	m^2

7th possibility



heat exchanger [1]

t1=	390	t2=	200		
t3=	370				
Q=	4479500	t4=	256.6815476		
∆Tlm=	35.212603	A=	848.0865031	C=	20004.70426

heat exchanger [2]

t1=	256.6815	t2=	180		
t3=	236.6815				
Q=	1856885.94	t4=	201.4170375		
∆Tlm=	20.7004358	A=	598.0183074	C=	16221.71369

heat exchanger [3]

t1=	440	t2=	236.6815		
t3=	350				
Q=	3712314.06	t4=	307.417355		
∆Tlm=	79.981642	A=	309.4305115	C=	10924.60959

heat exchanger [4]

t1=	307.4174	t2=	100		
t3=	287.4174				
Q=	2998678.4	t4=	200.3216979		
∆Tlm=	49.8072808	A=	401.3708237	C=	12770.13605

heat exchanger [5]

t1=	520	t2=	287.4174		
t3=	430				
Q=	2281321.6	t4=	424.1461513		
∆Tlm=	111.740647	A=	136.1081316	C=	6674.1888

heater [1]

Tin=	370	Tout=	400		
Tsin=	456.3	Tsout=	456.3		
Q=	790500	m(s)=	1030.101642		
∆Tlm=	70.2353953	A=	56.27504454	C=	3928.778575
Coolers				C(s)=	24363.96403

cooler [1]

Tin=	201.417	Tout=	150
Twin=	100	Twout=	180

Q=	1727611.2	m(w)=	21595.14		
ΔTlm=	33.7128081	A=	341.6330069	C=	11593.21629
				C(w)=	9458.67132

cooler [2]

Tin=	200.3217	Tout=	150		
Twin=	100	Twout=	180		
Q=		m(w)=	17612.595		
ΔTlm=	1409007.6	A=	284.9617534	C=	10397.76479
	32.9636658			C(w)=	7714.31661

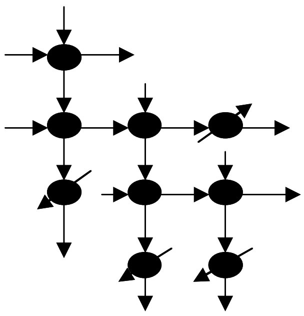
cooler [3]

Tin=	424.1462	Tout=	300		
Twin=	100	Twout=	180		
Q=	2954679.56	m(w)=	36933.4945		
ΔTlm=	221.33984	A=	88.99375613	C=	5172.300716
				C(w)=	16176.87059

total cost of heat exchangers =	66595.35239
total cost of coolers=	27163.2818
total cost of heaters=	3928.778575
total cost of cooling water=	33349.85852
total cost of steam=	24363.96403

J=	67482.5638	$/yr	101223845.7	ID/YR
A=	6434.86	ft^2	597.798494	m^2

8th possibility



heat exchanger [1]

t1=	390	t2=	180		
t3=	350				
Q=	5569200	t4=	224.25		
ΔTlm=	42.0892438	A=	882.1256139	C=	20482.65754

heat exchanger [2]

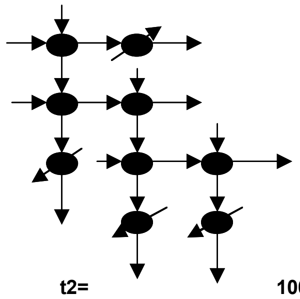
t1=	224.25	t2=	100		
t3=	204.25				
Q=	1668000	t4=	174.6071429		
ΔTlm=	41.4789046	A=	268.0880828	C=	10023.84978

heat exchanger [3]

t1=	440	t2=	204.25

t3=	400				
Q=	3132000	t4=	328.1428571		
∆Tlm=	74.2061573	A=	281.3782677	C=	10319.11317
heat exchanger [4]					
t1=	328.1429	t2=	200		
t3=	308.1429				
Q=	2849565.42	t4=	226.3727066		
∆Tlm=	23.0396508	A=	824.5395276	C=	19669.57302
heat exchanger [5]					
t1=	520	t2=	308.1429		
t3=	400				
Q=	2420434.59	t4=	418.3010679		
∆Tlm=	115.008908	A=	140.3041799	C=	6796.892641
heater [1]					
Tin=	400	Tout=	430		
Tsin=	456.3	Tsout=	456.3		
Q=	480000	m(s)=	625.488663		
∆Tlm=	39.4153083	A=	60.89004768	C=	4119.038325
				C(s)=	14794.05786
Coolers					
cooler [1]					
Tin=	174.6071	Tout=	150		
Twin=	100	Twout=	154.6071		
Q=	826798.56	m(w)=	15140.8619		
∆Tlm=	32.7407	A=	168.3528573	C=	7582.289099
				C(w)=	6631.697513
cooler [2]					
Tin=	226.3727	Tout=	150		
Twin=	100	Twout=	180		
Q=	2138435.6	m(w)=	26730.445		
∆Tlm=	48.1635872	A=	295.9961698	C=	10637.50309
				C(w)=	11707.93491
cooler [3]					
Tin=	418.3011	Tout=	300		
Twin=	100	Twout=	180		
Q=	2815566.18	m(w)=	35194.57725		
∆Tlm=	218.591584	A=	85.86991727	C=	5062.588999
total cost of heat exchangers=			67292.08615	C(w)=	15415.22484
total cost of heaters=			4119.038325		
total cost of coolers=			23282.38119		
total cost of cooling water=			33754.85726		
total cost of steam=			14794.05786		
J=	58018.2657 $/YR		87027398.52 ID/YR		
A=	5002.2 ft^2		464.70438 m^2		

9th possibility



heat exchanger [1]

t1=	390	t2=	100		
t3=	370				
Q=	4320000	t4=	261.4285714		
∆Tlm=	67.7232709	A=	425.2600269	C=	13220.89274

heat exchanger [2]

t1=	261.4286	t2=	180		
t3=	241.4286				
Q=	2012400.94	t4=	201.535715		
∆Tlm=	20.7583906	A=	646.2931777	C=	16995.18073

heat exchanger [3]

t1=	440	t2=	241.4286		
t3=	350				
Q=	3556799.06	t4=	312.971462		
∆Tlm=	80.4187279	A=	294.8566134	C=	10612.91212

heat exchanger [4]

t1=	312.9715	t2=	200		
t3=	292.9715				
Q=	2449799.03	t4=	225.4786777		
∆Tlm=	22.6289099	A=	721.7313401	C=	18159.06081

heat exchanger [5]

t1=	520	t2=	292.9715		
t3=	400				
Q=	2820200.98	t4=	401.5041607		
∆Tlm=	120	A=	156.6778319	C=	7262.273094

coolers

cooler [1]

Tin=	201.5357	Tout=	150		
Twin=	100	Twout=	180		
Q=	1515149.58	m(w)=	18939.36975		
∆Tlm=	33.7931009	A=	298.9070827	C=	10700.14758
cooler [2]				C(w)=	8295.443951
Tin=	225.4787	Tout=	150		
Twin=	100	Tout=	180		

Q=	2113403.6	m(w)=	26417.545		
∆Tlm=	47.703645	A=	295.3517981	C=	10623.60258
				C(w)=	11570.88471

cooler [3]

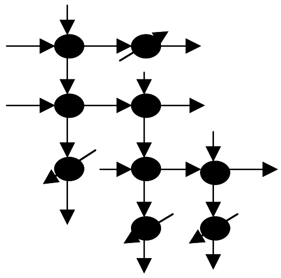
Tin=	401.5042	Tout=	300		
Twin=	100	Twout=	180		
Q=	2415799.96	m(w)=	30197.4995		
∆Tlm=	210.569124	A=	76.48477989	C=	4722.946837
				C(w)=	13226.50478

heater [1]

Tin=	370	Tout=	430		
Tsin=	456.3	Tsout=	456.3		
Q=	960000	m(s)=	1250.977326		
∆Tlm=	50.4939716	A=	95.06085271	C=	5381.07528
				C(s)=	29588.11572

total cost of heat exchangers =		66250.31949	
total cost of coolers=		26046.69701	
total cost of heaters=		5381.07528	
total cost of cooling water=		33092.83344	
total cost of steam=		29588.11572	
J=	72448.7583 $/YR	108673137.5	ID/YR
A=	7243.328 ft^2	672.9051712	m^2

10th possiblity



heat exchanger [1]

t1=	390	t2=	100
t3=	370		
Q=	4320000	t4=	261.4285714
∆Tlm=	67.7232709	A=	425.2600269
		C=	13220.89274

heat exchanger [2]

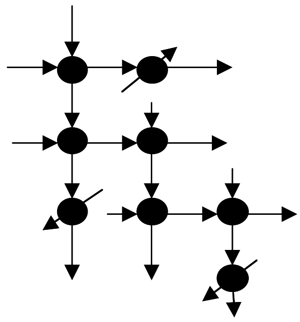
t1=	261.4286	t2=	200
t3=	241.4286		
Q=	1091643.61	t4=	228.9392068
∆Tlm=	24.1950005	A=	300.7904075
		C=	10740.54783

heat exchanger [3]

t1=	440	t2=	241.4286
t3=	400		
Q=	4178356.39	t4=	290.7729861
∆Tlm=	44.5088294	A=	625.8468179
		C=	16670.5095

heat exchanger [4]				
t1=	290.773	t2=	180	
t3=	270.773			
Q=	2973723.48	t4=	184.56859	
∆Tlm=	10.4511487	A=	1896.903758	
		C=	32426.13769	
heat exchanger [5]				
t1=	520	t2=	270.773	
t3=	350			
Q=	2595476.52	t4=	410.9463647	
∆Tlm=	154.60747	A=	111.9168223	
		C=	5934.788776	
Coolers				
cooler [1]				
Tin=	228.9392	Tout=	150	
Twin=	100	Twout=	180	
Q=	2652357.12	m(w)=	33154.464	
∆Tlm=	49.4677043	A=	357.4530299	
		C=	11912.40455	
		C(w)=	14521.65523	
cooler [2]				
Tin=	184.5686	Tout=	150	
Twin=	100	Twout=	164.5686	
Q=	967920.8	m(w)=	14990.58056	
∆Tlm=	32.7407	A=	197.0881907	
		C=	8334.209359	
cooler [3]		Cw=	6565.874286	
Tin=	410.9464	Tout=	300	
Twin=	100	Twout=	180	
Q=	2640524.32	m(w)=	33006.554	
∆Tlm=	215.102311	A=	81.83777943	
		C=	4918.586874	
		Cw=	14456.87065	
heaters				
heater [1]				
Tin=	370	Tout=	430	
Tsin=	456.3	Tsout=	456.3	
Q=	960000	ms=	1250.977326	
∆Tlm=	50.4939716	A=	95.06085271	
		C=	5381.07528	
		Cs=	29588.11572	
total cost of heat exchangers=			55031.43596	
total cost of coolers=			25165.20079	
total cost of heater =			5381.07528	
total cost of cooling water=			35544.40017	
total cost of steam=			29588.11572	
J=	73690.2871		110535430.6	ID/YR
A=	7451.385		692.2336665	m^2

11th possibility



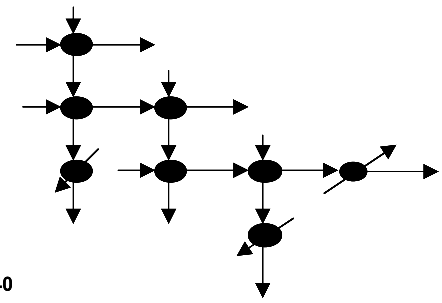
heat exchanger [1]			
t1=	440	t2=	100
t3=	400		
Q=	4800000	t4=	268.5714286
∆Tlm=	89.3800528	A=	358.0217173
		C=	11923.77211
heat exchanger [2]			
t1=	268.5714	t2=	200
t3=	248.5714		
Q=	1279856.39	t4=	222.8622432
∆Tlm=	21.399228	A=	398.7235405
		C=	12719.53312
heat exchanger [3]			
t1=	520	t2=	248.5714
t3=	400		
Q=	3990143.61	t4=	352.3469071
∆Tlm=	111.691423	A=	238.1647287
		C=	9336.723789
heat exchanger [4]			
t1=	352.3469	t2=	180
t4=	300		
Q=	1245856.22	t3=	218.0297991
∆Tlm=	127.024104	A=	65.38686677
		C=	4298.94967
heat exchanger [5]			
t1=	390	t2=	218.0298
t3=	350		
Q=	4323343.75	t4=	261.329055
∆Tlm=	41.6278393	A=	692.3801994
Coolers		C=	17712.29464
cooler [1]			
Tin=	222.8622	Tout=	150
Twin=	100	Twout=	180
Q=	2040141.6	m(w)=	25501.77
∆Tlm=	46.339515	A=	293.5063951
		C=	10583.72594
		C(w)=	11169.77526

cooler [2]

Tin=	261.3291	Tout=	150
Twin=	100	Twout=	180
Q=	3740657.76	m(w)=	46758.222
∆Tlm=	64.3994476	A=	387.2349735
		C=	12498.35306
heater		C(w)=	20480.10124
Tin=	400	Tout=	430
Tsin=	456.3	Tsout=	456.3
Q=	480000	m(s)=	625.488663
∆Tlm=	39.4153083	A=	60.89004768
		C=	4119.038325
		C(s)=	14794.05786

total cost of heat exchangers=	55991.27334	
total cost of coolers=	23082.079	
total cost of heaters=	4119.038325	
total cost of cooling water=	31649.8765	
total cost of steam=	14794.05786	
J= 54763.1734	82144760.13	ID/YR
A= 3368.32	312.916928	m^2

12th possibility



heat exchanger [1]

t1=	440
t2=	180
t3=	350
C=	14527.05

heat exchanger [2]

t1=	241.1	t2=	200
t3=	221.1		
Q=	555985	t4=	221.2433929
∆Tlm=	20.6154473	A=	179.7955972
		C=	7887.429236

heat exchanger [3]

t1=	520	t2=	221.1
t3=	400		
Q=	4714015	t4=	321.9321429
∆Tlm=	110.138223	A=	285.3393304
		C=	10406.02888

heat exchanger [4]

t1=	321.9321	t2=	100		
t4=	300				
Q=	3200000	t3=	187.4783185		
∆Tlm=	47.379167	A=	450.2682234	C=	13682.03899

heat exchanger [5]

t1=	390	t2=	187.4783	
t3=	370			
Q=	2920347.2	t4=	303.0849048	
ΔTlm=	54.4934398	A=	357.2720206	
		C=	11908.78482	

coolers

cooler [1]

Tin=	221.1	Tout=	150	
Twin=	100	Twout=	180	
Q=	1990800	m(w)=	24885	
ΔTlm=	45.4047153	A=	292.3044426	
		C=	10557.69944	
		C(w)=	10899.63	

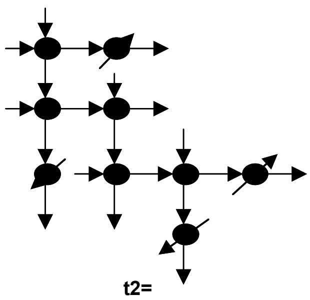
cooler [2]

Tin=	303.0849	Tout=	150	
Twin=	100	Twout=	180	
Q=	5143652.64	m(w)=	64295.658	
ΔTlm=	81.1287007	A=	422.6743102	
		C=	13172.60157	
		C(w)=	28161.4982	

heater

Tin=	370	Tout=	430	
Tsin=	456.3	Tsout=	456.3	
Q=	960000	m(s)=	1250.977326	
ΔTlm=	50.4939716	A=	95.06085271	
		C=	5381.07528	
		Cs=	29588.11572	
total cost of heat exchangers=			58411.33193	
total cost of coolers=			23730.301	
total cost of heaters=			29588.11572	
total cost of cooling water=			39061.1282	
total cost of steam=			29588.11572	
J=	79822.2188		119733328.2	ID/YR
A=	8513.2		790.87628	m^2

13 possibility



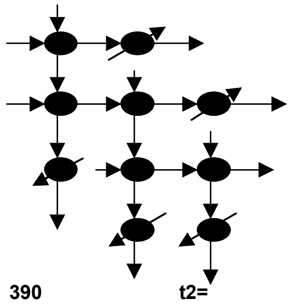
heat exchanger [1]

t1=	390	t2=	200
t3=	370		
Q=	4479500	t4=	256.682
ΔTlm=	35.2127675	A=	848.0825415

		C=	20004.64819
heat exchanger [2]			
t1=	256.682	t2=	180
t3=	236.682		
Q=	1856902.32	t4=	201.41705
ΔTlm=	20.7004419	A=	598.0234061
		C=	16221.79668
heat exchanger [3]			
t1=	520	t2=	236.682
t3=	350		
Q=	3712297.68	t4=	364.0211059
ΔTlm=	147.643759	A=	167.6240928
		C=	7562.578725
heat exchanger [4]			
t1=	364.0211	t2=	100
t4=	300		
Q=	1523702.18	t3=	195.2313863
ΔTlm=	183.953797	A=	55.22046667
		C=	3884.437051
heat exchanger [5]			
t1=	440	t2=	195.2314
t3=	400		
Q=	3276297.6	t4=	322.9893714
ΔTlm=	75.5714565	A=	289.0242561
		C=	10486.45312
coolers			
cooler [1]			
Tin=	201.4171	Tout=	150
Twin=	100	Twout=	180
Q=	1727614.56	m(w)=	21595.182
ΔTlm=	33.7128758	A=	341.6329851
		C=	11593.21585
		C(w)=	9458.689716
cooler [2]			
Tin=	322.9894	Tout=	150
Twin=	100	Twout=	180
Q=	4843703.2	m(w)=	60546.29
ΔTlm=	88.4983313	A=	364.8809441
		C=	12060.31786
heaters		c(w)=	37568.97295
heater [1]			
Tin=	370	Tout=	400
Tsin=	456.3	Tsout=	456.3
C=	3928.77	C(s)=	24363.964
heater [2]			
Tin=	400	Tout=	430
Tsin=	456.3	Tsout=	456.3
C=	4119.038	c(s)=	14794.06

total cost of heat exchangers=		58159.91376	
total cost of coolers=		23653.53371	
total cost of I	95171.8122	8047.808	
total cost of (	11413.0176	47027.66266	
total cost of steam=		39158.024	
J=		142757718.3	ID/YR
A=		1060.269335	m^2

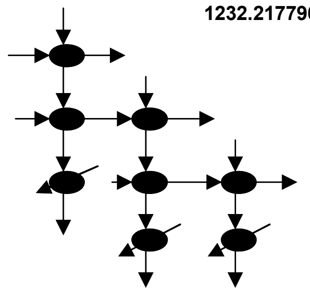
14th possibilty



heat exchanger [1]			
t1=	390	t2=	200
t3=	370	t4=	256.682
C=	200004.648		
heat exchanger [2]			
t1=	256.682	t2=	100
t3=	236.682		
Q=	2186912	t4=	191.5953333
∆Tlm=	47.051178	A=	309.8628758
heat exchanger [3]		C=	10933.76594
t1=	440	t2=	236.682
t3=	400		
Q=	2613088	t4=	346.6754286
∆Tlm=	69.1948392	A=	251.7613578
heat exchanger [4]		C=	9652.981806
t1=	346.6754	t2=	180
t3=	300		
Q=	3931200	t4=	206.2754
∆Tlm=	35.5039398	A=	738.1715976
heat exchqnger [5]		C=	18406.12821
t1=	520	t2=	300
t3=	350		
Q=	1638000	t4=	451.1764706
∆Tlm=	160.404198	A=	68.07801869
coolers		C=	4404.252292
cooler [1]			
Tin=	191.5953	Tout=	150
Twin=	100	Twout=	171.5953
Q=	1397602.08	m(w)=	19520.86352
∆Tlm=	32.7407	A=	284.5799628
		C=	10389.40402
cooler [2]		C(w)=	8550.138222
Tin=	206.2754	Tout=	150

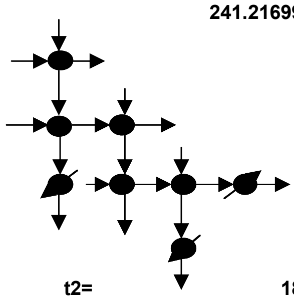
Twin=	100	Twout=	180
Q=	1575711.2	m(w)=	19696.39
∆Tlm=	36.8743763	A=	284.8791596
		C=	10395.95646
cooler [3]		C(w)=	8627.01882
Tin=	451.1765	Tout=	300
Twin=	100	Twout=	180
Q=	3598000.7	m(w)=	44975.00875
∆Tlm=	233.785211	A=	102.6013202
		C=	8951.073198
heaters		C(w)=	19699.05383
heater [1]			
Tin=	370	Tout=	400
Tsin=	456.3	Tsout=	456.3
C=	3928.778	C(s)=	24363.964
heater [2]			
Tin=	400	Tout=	430
Tsin=	456.3	Tsout=	456.3
C=	4119.038	C(s)=	14794.06
total cost of heat exchangers=			243401.7764
total cost of coolers=			29736.43368
total cost of heaters=			8047.816
total cost of cooling water=			36876.21087
total cost of steam=			39158.024
J=	104152.837 $/yr		156229256.2 ID/YR
A=	13263.916 ft^2		1232.217796 m^2

15 th possibility



heat exchanger [1]			
t1=	390	t2=	180
t3=	350		
Q=	5569200	t4=	224.25
∆Tlm=	42.0892438	A=	882.1256139
heat exchanger [2]		C=	20482.65754
t1=	224.25	t2=	200
t3=	204.25		
Q=	111987.5	t4=	220.9170387
∆Tlm=	20.4550934	A=	36.49865185
heat exchanger [3]		C=	3029.940766
t1=	440	t2=	204.25
t3=	400		
Q=	5158012.5	t4=	255.7852679

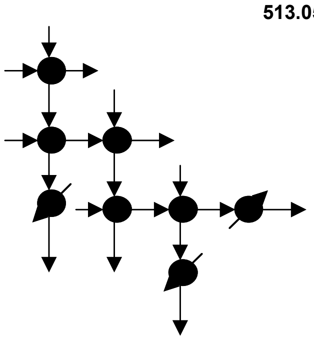
ΔTlm=	45.5243203		A=	755.3490036			
heat exchanger [4]			C=	18661.93364			
t1=	255.7853		t2=	100			
t3=	235.7853						
Q=	2172564.8		t4=	178.1937			
ΔTlm=	42.681		A=	339.34925			
heat exchanger [5]			C=	11546.65475			
t1=	520		t2=	235.7853			
t3=	430						
Q=	3107435.2		t4=	389.4354958			
ΔTlm=	119.001491		A=	174.0838242			
			C=	7736.118177			
Coolers							
cooler [1]							
Tin=	220.917		Tout=	150			
Twin=	100		Twout=	180			
Q=	2382811.2		m(w)=	29785.14			
ΔTlm=	45.3068569		A=	350.6181866			
			C=	11775.21127			
cooler [2]			Cw=	13045.89132			
Tin=	178.1937		Tout=	150			
Twin=	100		Twout=	158.1937			
Q=	789423.6		m(w)=	13565.44781			
ΔTlm=	32.7407		A=	160.7425618			
			C=	7374.737657			
cooler [3]			Cw=	5941.666139			
Tin=	389.4355		Tout=	300			
Twin=	100		Twout=	180			
Q=	2128564.9		m(w)=	26607.06125			
ΔTlm=	204.681504		A=	69.32933537			
			C=	4452.647003		Cw=	11653.89283
total cost of heat exchangers=				61457.30488			
total cost of coolers=				23602.59593			
total cost of cooling water=				30641.45029			
J=	39147.4404	$/yr		58721160.55	ID/YR		
A=	2596.5231	ft^2		241.216996	m^2		
16th possibility							



heat exchanger [1]			
t1=	390	t2=	180
t3=	350	t4=	224.25
heat exchanger [2]		C=	20482.65754
t1=	224.25	t2=	200

t3=	204.25	t4=	220.9		
heat exchanger [3]		C=	3029.940766		
t1=	520	t2=	204.25		
t3=	400				
Q=	5158012.5	t4=	303.2767857		
ΔTlm=	109.177851	A=	314.9608626		
heat exchanger [4]		C=	11041.34548		
t1=	303.2768	t2=	100		
t4=	300				
Q=	3200000	t3=	168.8230185		
ΔTlm=	21.5281783	A=	990.9493057		
		C=	21963.36642		
heat exchanger [5]					
t1=	440	t2=	168.823		
t3=	400				
Q=	3698832	t4=	307.8988571		
ΔTlm=	79.5061967	A=	310.1504162		
		C=	10939.85247		
Coolers					
cooler [1]		11775.21127		Cw=	13045.89132
cooler [2]					
Tin=	307.8989	Tout=	150		
Twin=	100	Twout=	180		
Q=	4421169.2	m(w)=	55264.615		
ΔTlm=	82.9402486	A=	355.3698213		
		C=	11870.70113		
Heaters		Cw=	24205.90137		
heater [1]					
Tin=	400	Tout=	430		
Tsin=	456.3	Tsout=	456.3		
C=	4119.038	Cs=	14794.06		
total cost of heat exchangers=			67457.16267		
total cost of coolers=			23645.9124		
total cost of heaters=			4119.038		
total cost of cooling water=			37251.79269		
total cost of steam=			14794.06		
J=	61568.064		92352096	ID/YR	
A=	5522.6275		513.0520948	m^2	

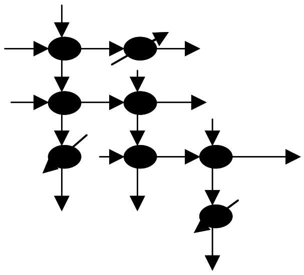
17th possibility



heat exchanger [1]			
t1=	390	t2=	180
t3=	350	t4=	224.25
heat exchanger [2]		C=	20482.65754
t1=	224.25	t2=	200
t3=	204.25	t4=	220.9
heat exchanger [3]		C=	3029.94
t1=	520	t2=	204.25
t3=	400		
Q=	5158012.5	t4=	303.2767857
∆Tlm=	109.177851	A=	314.9608626
heat exchanger [4]		C=	11041.34548
t1=	303.2768	t2=	100
t4=	300		
Q=	77987.84	t3=	104.87424
∆Tlm=	199.200212	A=	2.610032022
heat exchanger [5]		C=	622.3798817
t1=	440	t2=	104.8742
t3=	400		
Q=	4722012.8	t4=	271.3566857
∆Tlm=	88.6967323	A=	354.9182084
		C=	11861.64747
Coolers			
cooler [1]			
Tin=	220.9	Tout=	150
Twin=	100	Twout=	180
		C=	11775.21127
cooler [2]		Cw=	13045.89132
Tin=	271.3567	Tout=	150
Twin=	100	Twout=	180
Q=	3397987.6	m(w)=	42474.845
∆Tlm=	68.6135127	A=	330.1572793
		C=	11357.96617
heaters		Cw=	18603.98211
heater [1]			
Tin=	400	Tout=	430
C=	4119.038	Cs=	14794.06
total cost of heat exchangers=			47037.97038
total cost of coolers=			23133.17744
total cost of heaters=			4119.038
total cost of cooling water=			31649.87343
total cost of steam=			14794

J=	53872.892	80809338.02	ID/YR
A=	2588.9499	240.5134457	m^2

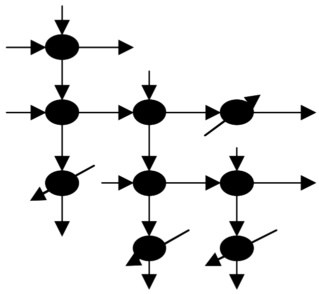
18th possibility



heat exchanger [1]					
t1=	390	t2=	100		
t3=	370				
C=	13267				
heat exchanger [2]					
t1=	261.4286	t2=	180		
t3=	241.4286				
Q=	2012400.94	t4=	201.535715		
∆Tlm=	20.7583906	A=	646.2931777		
heat exchanger [3]		C=	16995.18073		
t1=	520	t2=	241.4286		
t3=	350				
Q=	3556799.06	t4=	370.5546612		
∆Tlm=	148.627483	A=	159.5397652		
heat exchanger [4]		C=	7341.577936		
t1=	370.5547	t2=	200		
t4=	300				
Q=	1679201.86	t3=	263.7268258		
∆Tlm=	103.376359	A=	108.2905143		
heat exchanger [5]		C=	5818.6508		
t1=	440	t2=	263.7268		
t3=	400				
Q=	3590798.82	t4=	311.757185		
∆Tlm=	43.8928279	A=	545.3888469		
Coolers		C=	15349.41386	C(w)=	24797.37876
cooler [1]					
Tin=	201.5357	Tout=	150		
C=	11593.215	Cw=	9458.689		
cooler [2]					
Tin=	311.7572	Tout=	150		
Twin=	100	Twout=	180		
Q=	4529201.6	m(w)=	56615.02		
∆Tlm=	84.3781691	A=	357.8494018		
heater [1]		C=	11920.32844		
Tin=	370	Tout=	430		
C=	5381.0753	C(s)=	29588.116		
total cost of heat exchangers=			58771.82332		
total cost of coolers=			23513.54344		
total cost of heater=			5381.0753		

total cost of cooling water=			34256.06776
total cost of steam=			29588.116
J=	72610.828		108916241.9 ID/YR
A=	7270.354		675.4158866 m^2

19th possibility



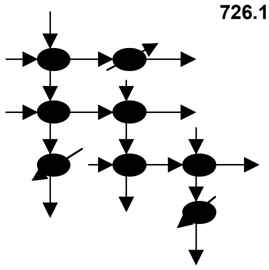
heat exchanger [1]			
t1=	440	t2=	200
t3=	400		
Q=	5270000	t4=	251.7857143
ΔTlm=	45.639515	A=	769.8007593
heat exchanger [2]		C=	18875.35139
t1=	251.7857	t2=	100
t3=	231.7857		
Q=	2108571.2	t4=	176.4795857
ΔTlm=	42.1083578	A=	333.8325706
heat exchanger [3]		C=	11433.65986
t1=	390	t2=	231.7857
t3=	370		
Q=	2211428.8	t4=	324.1836667
ΔTlm=	47.3074087	A=	311.6395314
heat exchanger [4]		C=	10971.33737
t1=	324.1837	t2=	180
t3=	304.1837		
Q=	4068258.01	t4=	203.1045925
ΔTlm=	21.5149767	A=	1260.597232
heat exchanger [5]		C=	25375.45592
t1=	520	t2=	304.1837
t3=	350		
Q=	1500941.99	t4=	456.9352106
ΔTlm=	161.222006	A=	62.06522411
coolers		C=	4166.554252
cooler [1]			
Tin=	176.4796	Tout=	150
C=	7374.73	C(w)=	5941.666
cooler [2]			
Tin=	203.1046	Tout=	150
Twin=	100	Twout=	180
Q=	1784314.56	m(w)=	22303.932

∆Tlm=	34.8389948	A=	341.4401148
		C=	11589.2884
cooler [3]		C(w)=	9769.122216
Tin=	456.9352	Tout=	300
Twin=	100	Twout=	180
Q=	3735057.76	m(w)=	46688.222
∆Tlm=	236.384624	A=	105.3384295
		C=	5722.952585
heater[1]		C(w)=	20449.44124
Tin=	370	Tout=	430
C=	5381.0753	C(s)=	29588.116

total cost of heat exchangers=	70822.3588
total cost of coolers=	24686.97099
total cost of heaters=	5381.0753
total cost of cooling water=	36160.22945
total cost of steam=	29588.116

J=	75837.386	113756078.9	ID/YR
A=	7816.737	726.1748673	m^2

20 th possibility



heat exchanger [1]			
t1=	390	t2=	100
t3=	370	t4=	261.4286
C=	13267		
heat exchanger [2]			
t1=	261.4286	t2=	200
t3=	241.4286		
Q=	1091643.61	t4=	228.9392068
∆Tlm=	24.1950005	A=	300.7904075
heat exchanger [3]		C=	10740.54783
t1=	520	t2=	241.4286
t3=	400		
Q=	4178356.39	t4=	344.4388071
∆Tlm=	111.289044	A=	250.3005535
heat exchanger [4]		C=	9619.336788
t1=	344.4388	t2=	180
t4=	300		
Q=	1057643.44	t3=	212.2845983
∆Tlm=	125.979399	A=	55.96912151
heat exchanger [5]		C=	3915.950005
t1=	440	t2=	212.2846

t3=	350		
Q=	4511556.5	t4=	278.872982
ΔTlm=	77.7072915	A=	387.0556133
		C=	12494.87934

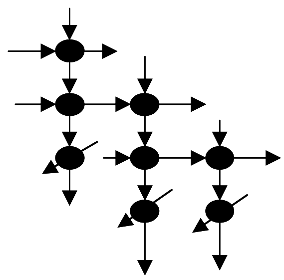
coolers

cooler [1]

Tin=	228.9392	Tout=	150
Twin=	100	Twout=	180
Q=	2652357.12	m(w)=	33154.464
ΔTlm=	49.4677043	A=	357.4530299
		C=	11912.40455
cooler [2]		C(w)=	14521.65523
Tin=	278.873	Tout=	150
Twin=	100	Twout=	180
Q=	3608444	m(w)=	45105.55
ΔTlm=	71.6809245	A=	335.6024424
		C=	11469.99192
heater [1]		C(w)=	19756.2309
Tin=	370	Tout=	430
C=	5381.0753	C(s)=	29588.116
total cost of heat exchangers=			50037.71396
total cost of coolers=			23382.39648
total cost of heater=			5381.0753
total cost of cooling water=			34277.88613
total cost of steam=			29588.116

J=	71746.1207	107619181.1	ID/YR
A=	7126.626	662.0635554	m^2

21st possibility



heat exchanger [1]

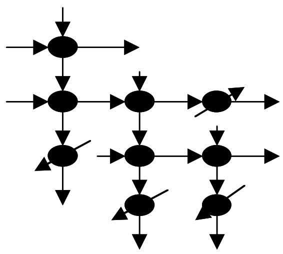
t1=	440	t2=	200
t3=	400		
C=	18875.4		

heat exchanger [2]

t1=	252	t2=	180
t3=	232		
Q=	1703520	t4=	191.16
ΔTlm=	15.1526497	A=	749.4926797
heat exchanger [3]		C=	18574.98542
t1=	390	t2=	232

t3=	350				
Q=	3865680	t4=	274.95		
ΔTlm=	41.4575087	A=	621.6292495		
heat exchanger [4]		C=	16603.01304		
t1=	274.4927	t2=	100		
t3=	254.4927				
Q=	2471883.2	t4=	200.9247476		
ΔTlm=	49.9954301	A=	329.6145527		
heat exchanger [5]		C=	11346.76005		
t1=	520	t2=	245.4927		
t3=	430				
Q=	2952116.8	t4=	395.961479		
ΔTlm=	117.655913	A=	167.2740302		
coolers		C=	7553.098647		
cooler [1]					
Tin=	191.16	Tout=	150		
C=	10389.404	C(w)=	8550.138		
cooler [2]					
Tin=	200.9247	Tout=	150		
C=	11593.22	C(w)=	9548.689		
cooler [3]					
Tin=	395.9615	Tout=	300		
Twin=	100	Twout=	180		
Q=	2283883.7	m(w)=	28548.54625		
ΔTlm=	207.878629	A=	73.24413954		
		C=	4601.842738	C(w)=	12504.26326
total cost of heat exchangers=			72953.25716		
total cost of coolers=			26584.46674		
total cost of cooling water=			30603.09026		
J=	40556.8626		60835293.97 ID/YR		
A=	2754.189		255.8641581 m^2		

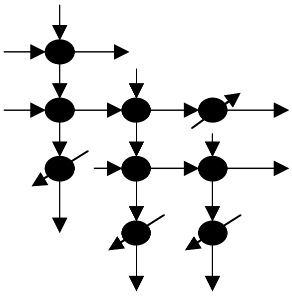
22nd possibility



heat exchanger [1]			
t1=	440	t2=	180
t3=	350		
heat exchanger [2]			
t1=	241	t2=	200
t3=	221		

Q=	553350	t4=	221.2375		
ΔTlm=	20.6125591	A=	178.9685587		
heat exchanger [3]				C=	14533.77
t1=	390	t2=	221		
t3=	370				
Q=	3926150	t4=	273.1502976		
ΔTlm=	33.5458865	A=	780.254632		
heat exchanger [4]				C=	7865.640421
t1=	273.1503	t2=	100		
t3=	253.1503				
Q=	2450404.8	t4=	200.2215857		
ΔTlm=	49.7760184	A=	328.1908139		
heat exchanger [5]				C=	19028.73235
t1=	520	t2=	253.1503		
t3=	430				
Q=	2829595.2	t4=	401.1094454		
ΔTlm=	116.588319	A=	161.7998111		
coolers				C=	11317.32785
cooler [1]					
Tin=	221	Tout=	150		
Twin=	100	Twout=	180		
Q=	1988000	m(w)=	24850		
ΔTlm=	45.3512594	A=	292.2373824	C=	7403.802932
cooler [2]					
Tin=	200.2216	Tout=	150		
Twin=	100	Twout=	180		
C=	11593.22	C(w)=	9548.689		
cooler [3]				C=	10556.24608
Tin=	401.1094	Tout=	300	C(w)=	10884.3
Twin=	100	Twout=	180		
Q=	2406403.72	m(w)=	30080.0465		
ΔTlm=	210.378219	A=	76.25642764		
heater					
Tin=	370	Tout=	400		
Tsin=	456.3	Tsout=	456.3		
Q=	790500	m(s)=	1030.101642		
ΔTlm=	70.2353953	A=	56.27504454	C=	4714.481306
				C(W)=	13175.06037
total cost of heat exchangers=			60149.27355		
total cost of coolers=			26863.94739		
total cost of heaters=			3928.778575		
total cost of cooling water=			33608.04937		
total cost of steam=			24363.96403	C=	3928.778575
				C(s)=	24363.96403
J=	67066.2134		106015615	ID/YR	
A=	6368.828		591.6641212	m^2	

23rd possibility

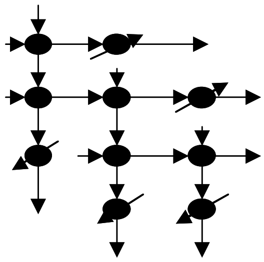


heat exchanger [1]

t1=	440	t2=	180		
t3=	350	t4=	241		
heat exchanger [2]					
t1=	241	t2=	100		
t3=	221				
Q=	1936000	t4=	171.8571429		
∆Tlm=	40.5467252	A=	318.3158838	C=	14533.77
heat exchanger [3]					
t1=	390	t2=	221		
t3=	370				
Q=	2384000	t4=	319.047619		
∆Tlm=	49.0951678	A=	323.7250028	C=	11111.76455
heat exchanger [4]					
t1=	319.0476	t2=	200		
t3=	299.0476				
Q=	2609904.26	t4=	241.371878		
∆Tlm=	29.4026503	A=	591.7616799	C=	11224.67539
heat exchanger [5]					
t1=	520	t2=	299.0476		
t3=	400				
Q=	2660095.74	t4=	408.2312714		
∆Tlm=	114.506706	A=	154.872778	C=	16119.67003
coolers					
cooler [1]					
Tin=	171.8571	Tout=	150		
C=	6354.984	C(w)=	5188.615		
cooler [2]				C=	7211.956481
Tin=	241.3719	Tout=	150		
Twin=	100	Twout=	180		
Q=	3070095.84	m(w)=	38376.198		
∆Tlm=	55.4918831	A=	368.8342236		
cooler [3]					
Tin=	408.2313	Tout=	300		
Twin=	100	Twout=	180		
Q=	2575904.94	m(w)=	32198.81175	C=	12138.54888
∆Tlm=	213.805097	A=	80.31941181	C(w)=	16808.77472
heater					
Tin=	370	Tout=	430		

C=	5381.0753	C(s)=	29588.116		
				C=	4863.628067
total cost of heat exchangers=			60201.83645	C(w)=	14103.07955
total cost of coolers=			23357.16094		
total cost of heater=			5381.0753		
total cost of cooling water=			36100.46927		
total cost of steam=			29588.116		
J=	74582.5925	\$/yr	109311436	ID/YR	
A=	7602.37	ft^2	706.260173	m^2	

24th possibility



hear exchanger [1]					
t1=	440	t2=	100		
t3=	400				
Q=	4800000	t4=	268.5714286		
∆Tlm=	89.3800528	A=	358.0217173		
heat exchanger [2]					
t1=	268.5714	t2=	200		
t3=	248.5714				
Q=	1279856.39	t4=	222.8622432		
∆Tlm=	21.399228	A=	398.7235405	C=	11923.77211
heat exchanger [3]					
t1=	390	t2=	248.5714		
t3=	370				
Q=	3199643.61	t4=	294.7725116		
∆Tlm=	31.2934442	A=	681.6430074	C=	12719.53312
heat exchanger [4]					
t1=	294.7725	t2=	180		
t3=	274.7725				
Q=	3104747.1	t4=	202.3693125		
∆Tlm=	21.1625556	A=	978.0630643	C=	17546.97408
heat exchanger [5]					
t1=	520	t2=	274.7725		
t3=	350				
Q=	2464452.9	t4=	416.4515588		
∆Tlm=	155.409681	A=	105.7185495	C=	21791.55188
Coolers					
cooler [1]					
Tin=	222.8622	Tout=	150		

Twin=	100	Twout=	180		
Q=	2331590.4	m(w)=	29144.88	C=	5735.334627
∆Tlm=	46.339515	A=	335.4358802		

cooler [2]

Tin=	202.3693	Tout=	150		
Twin=	100	Twout=	180		
Q=	1759608.48	m(w)=	21995.106	C=	11466.57599
∆Tlm=	34.352292	A=	341.4829849	C(w)=	12765.45744

cooler [3]

Tin=	416.4516	Tout=	300		
Twin=	100	Twout=	180		
Q=	2771548.08	m(w)=	34644.351	C=	11590.16145
∆Tlm=	217.717458	A=	84.86681481	C(w)=	9633.856428

Heaters

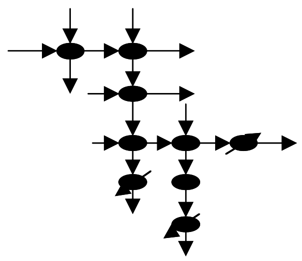
heater [1]

Tin=	400	Tout=	430		
Tsin=	456.3	Tsout=	456.3	C=	5027.022001
				C(w)=	15174.22574

heater [2]

Tin=	370	Tout=	400		
Tsin=	456.3	Tsout=	456.3		
				C=	4119.038
				C(s)=	14794.06
total cost of heat exchangers =			69717.16582		
total cost of coolers=			28083.75944		
total cost of heaters=			8047.816		
total cost of cooling water=			37573.53961	C=	3928.778
total cost of steam=			39158.024	C(s)=	24363.964
J=	87316.4377	$/yr	124507757		
A=	9886.59	ft^2	918.464211		

25th possibility



heat exchanger [1]					
t1=	520				
t4=	300			t2=	200
Q=	5236000	t3=	398.7096774		
		∆Tlm=	110.3029245	A=	316.461842
heat exchanger [2]				C=	11072.88668
t1=	440	t2=	398.7079		
t3=	400				
Q=	34046.835				
t4=	438.784042				
∆Tlm=	40.0380587	A=	5.669078551		
		C=	991.2324911		
heat exchanger [3]					
t1=	438.784	t2=	180		
t3=	350				
Q=	5569200				
t4=	239.884				
∆Tlm=	73.3880475	A=	505.9134457		
		C=	14672.82634		
heat exchanger [4]					
t1=	239.884	t2=	100		
t3=	219.884				
Q=	1918144				
t4=	171.378857				
∆Tlm=	40.3836293	A=	316.6537257		
		C=	11076.91455		
heat exchanger [5]					
t1=	390	t2=	219.884		
t3=	370				
Q=	2401856				
t4=	318.51619				
∆Tlm=	49.2786207	A=	324.9355017		
		C=	11249.83992		
Coolers					
cooler [1]					
Tin=	171.3789	Tout=	150		
Twin=	100	Tw out=	151.3789		
Q=	598609.2				
∆Tlm=	32.7407	A=	121.8889027		
C=	6246.64096	Cw=	5103.083748		
cooler [2]					
Tin=	318.5162	Tout=	150		
Twin=	100	Twout=	180		
Q=	5662144.32	mw=	70776.804		
∆Tlm=	118.812854	A=	317.706609		
C=	11098.9985	Cw=	31000.24015		
heater					
Tin=	370	Tout =	430		

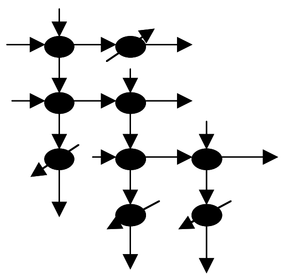
Tsin=	456.3		Twout=	456.3
Q=	960000		ms=	1250.977326
ΔTlm=	50.4939716		A=	95.06085271
C=	5381.07528		Cs=	29588.11572
J=	72870.4811	$/yr		115788809 ID/YR
A=	7313.7366	ft^2		679.4461301 m^2

stru.no.	cost (ID)	Area (m^2)
1	58177477	237.50585
2	171360844	1437.4843
3	241437190	2545.4061
4	106286066	648.45135
5	88020299	473.5754
6	100088917	586.66907
7	101223846	597.79549
8	87027399	464.704
9	108673138	672.90517
10	110535431	692.23367
11	82144760	312.91693
12	119733328	790.876
13	142757718	1060.2693
14	156229256	1232.2178
15	58721161	241.217
16	92352096	513.05209
17	58618338	240.51348
18	108916242	675.41589
19	1131756079	726.17457
20	107619181	662.06356
21	60835294	255.8641
22	106015615	591.66412
23	109311436	706.26017
24	124507757	918.46421
25	115788809	679.44613

the first is the optimum. 58177477 237.50585

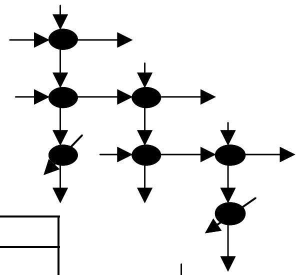
Rudd Heuristic

1 st possibility



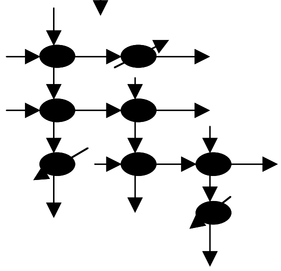
cost=	108673138	ID/YR
A=	672.90517	m^2

2 nd possibility



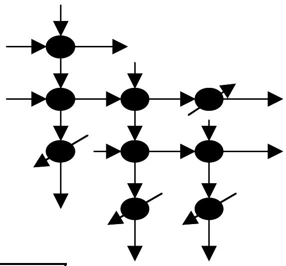
cost=	119733328	ID/YR
A=	790.876	m^2

3 rd possibility



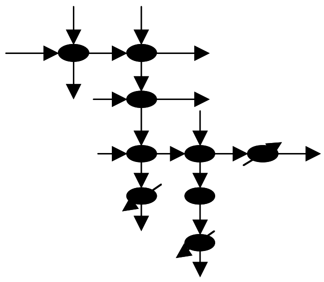
cost=	107619181	ID/YR
A=	662.06356	m^2

4 th possibility



cost=	109311436	ID/YR
A=	706.26017	m^2

5 th possibility



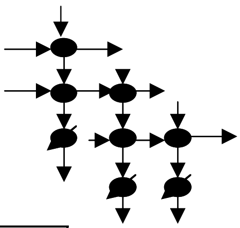
cost=	115788805	ID/YR
A=	679.44613	m^2

POS.NU.	COST (ID)	Area (m^2)
1	108673138	672.90517
2	119733328	790.876
3	107619181	662.06356
4	109311436	706.26017
5	115788805	679.44613

Min. 107619181 662.06356

Linnhoff Heuristic

it give just one possibility



J=	60835294	ID/YR
A=	255.8641	M^2

IT IS SO CLOSE TO THE OPTIMUM.

Appendix B3
SYSTEM C
PINCH METHOD

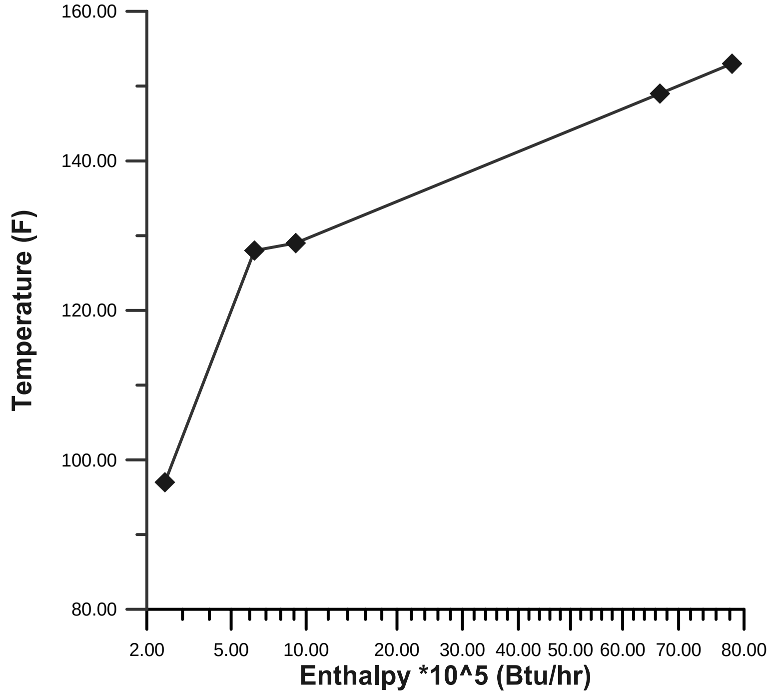
stream no.	condition	m.Cp	Tin (F)	Tout (F)
1	cold	4893	77	133
2	cold	2173	77	129
3	cold	5.0*10^5	156	196
4	hot	1.23*10^4	244	77
5	hot	2.75*10^5	176	128
6	hot	1046	244	129

The intervals heat duty

Q1= 3.73*10^5
Q2= -19400000
Q3= 66.3^10^5
Q4= 11.3*10^5
Q5= 56.25*10^5
Q6= 2.8*10^5
Q7= 1.622*10^5
Q8= 2.46*10^5

Enthalpy values and cumalative H for hot streams

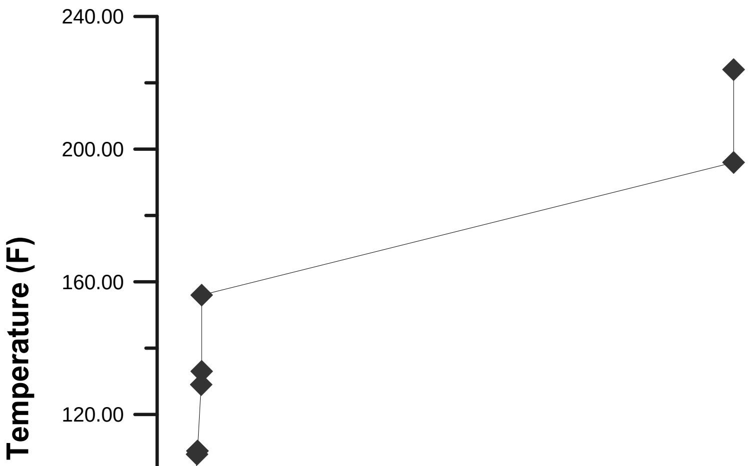
Temp.			H acumalative	
77	H=0		0	
97	H=2.46*10^5		2.46*10^5	
128	H=3.813*10^5		6.273*10^5	
129	H=2.87*10^5		9.14*10^5	
149	H=5.766*10^6		6.68*10^6	
153	H=1.153*10^6		7.883*10^6	
176	H=6.63*10^6		1.446*10^7	
216	H=5.33*10^5		1.499*10^7	
244	H=3.73*10^5		1.5363*10^7	



Enthalpy values and cumalative H for cold streams

Temp.			H acc.
77	H1=	162.87*10^5	162.87*10^5
108	H2=	219046	16506046
109	H3=	7066	16513112
129	H4=	141320	16654432
133	H5=	19572	16674004
156	H6=	0	16674004
196	H7=	20000000	36674004
224	H8=	0	36674004

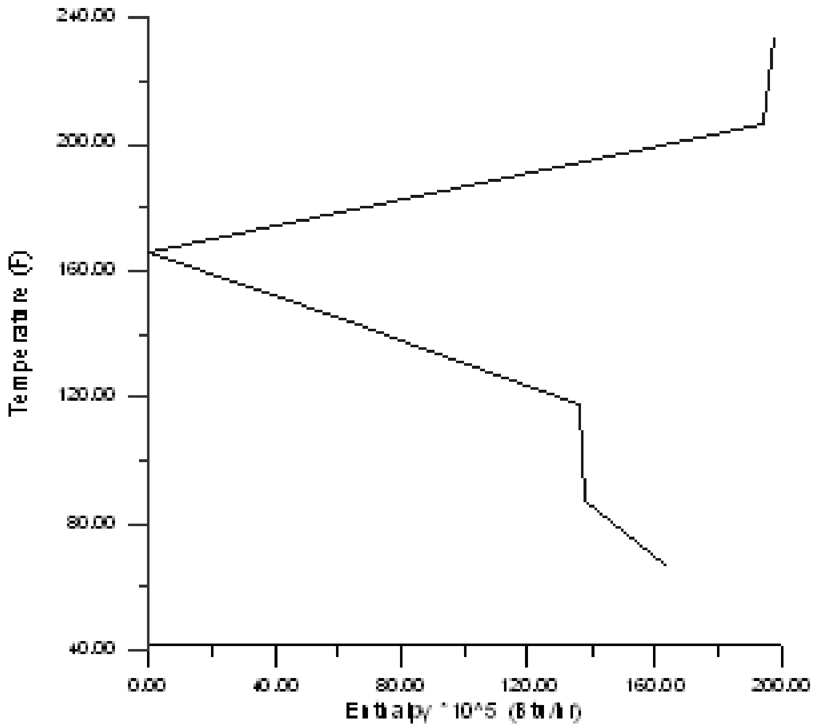
B3-2



To draw the grand composite curve

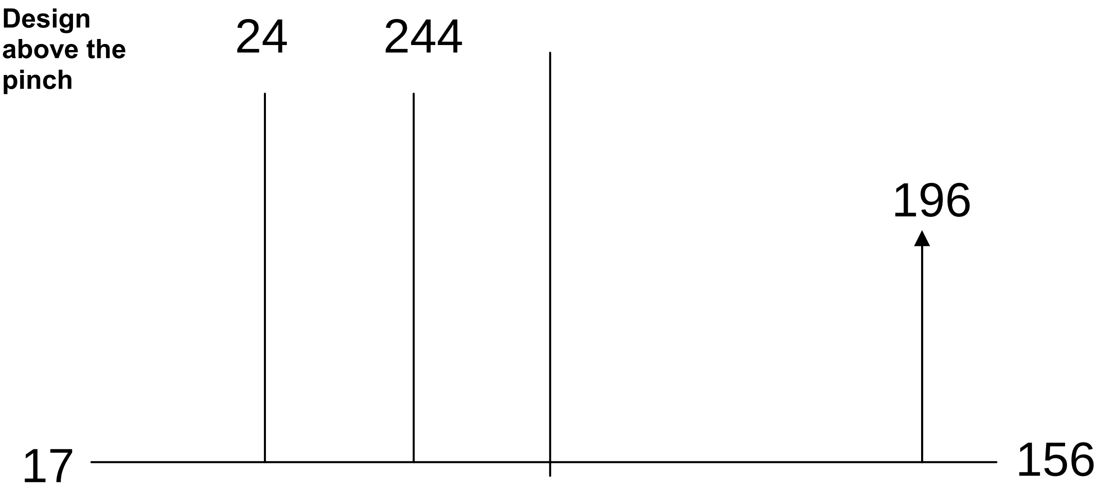
Avg. tem.	Hacc.
67	162.87
87	138.27
118	136.65
119	133.85
139	77.6
143	66.3
166	0
206	194
234	197.73

B3-3

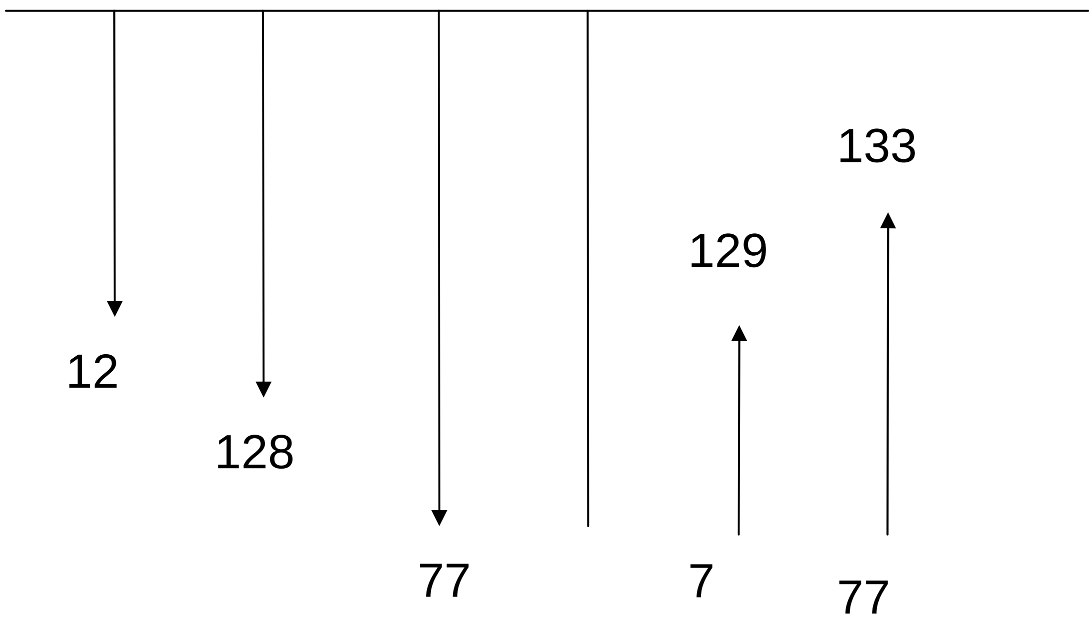


The pinch temperature is 166 F.

Design above the pinch



B3-4



Design below the pinch

The matching of streams according to the convergence in capacity flow rate.
the structure is given in chapter four. Figure (4.2)

B3-5

The calculations for this network

Above

heat exchanger {1}						
Q=	836400	t3=	157.67			
ΔTlm=	45.378271	A=	122.87819	C=	6277.012	$/yr
heat exchanger {2}					9415518	ID
Q=	71128	t3=	157.8			
ΔTlm=	43.902832	A=	10.800822	C=	1459.292	$/YR
heater					2188938	ID
Tin=	157.8	Tout=	196			
Tsin=	540	Tsout=	540			
Q=	19100000					
ΔTlm=	362.76485	A=	263.25594	C=	9915.051	$/YR
λ=	656.6	ms=	29089.248		14872576	ID
				Cs=	254821.8	$/YR

Below

					3.82E+08	ID
heat exchanger {3}						
Q=	112996	t4=	166.8	C=	1506.966	$/YR
ΔTlm=	66.10678	A=	11.395301		2260449	ID
heat exchanger {4}						
Q=	274008	t4=	175	C=	2548.804	$/YR
ΔTlm=	66.766423	A=	27.35986		3823205	ID

Coolers

cooler {1}			
Tin=	166.8	Tout=	77
Twin=	100	Twout=	146.8
Q=	1104540		
ΔTlm=	21.465071	A=	343.05035

mw=	23601.282	Cw=	10337.362	$/yr		
			15506042	ID/YR		
cooler {2}				C=	11622.05	$/YR

B3-6

Tin=	175	Tout=	129		17433076	ID
Twin=	100	Tw out=	155			
Q=	48116					
ΔTlm=	24.221966	A=	13.243076	C=	1649.155	$/YR
mw=	874.83636	Cw=	383.17833	$/YR	2473732	ID/YR
			574767.49	ID/YR		
cooler {3}						
Tin=	176	Tout=	128			
Twin=	100	Twout=	156			
Q=	13200000					
ΔTlm=	23.776107	A=	3701.1946	C=	48425.4	$/YR
mw=	235714.29	Cw=	103242.86		72638097	ID
			154864286	ID/YR		
total cost of heat exchangers=			17688110			
total cost of heaters=			14872576			
total cost of coolers=			170945096			
total cost of steam=			382232714			
total cost of cooling water=			170945096			

J=	377125.6	$/YR	565688369	ID/YR
A=	113247.5	ft^2	10520.696	m^2

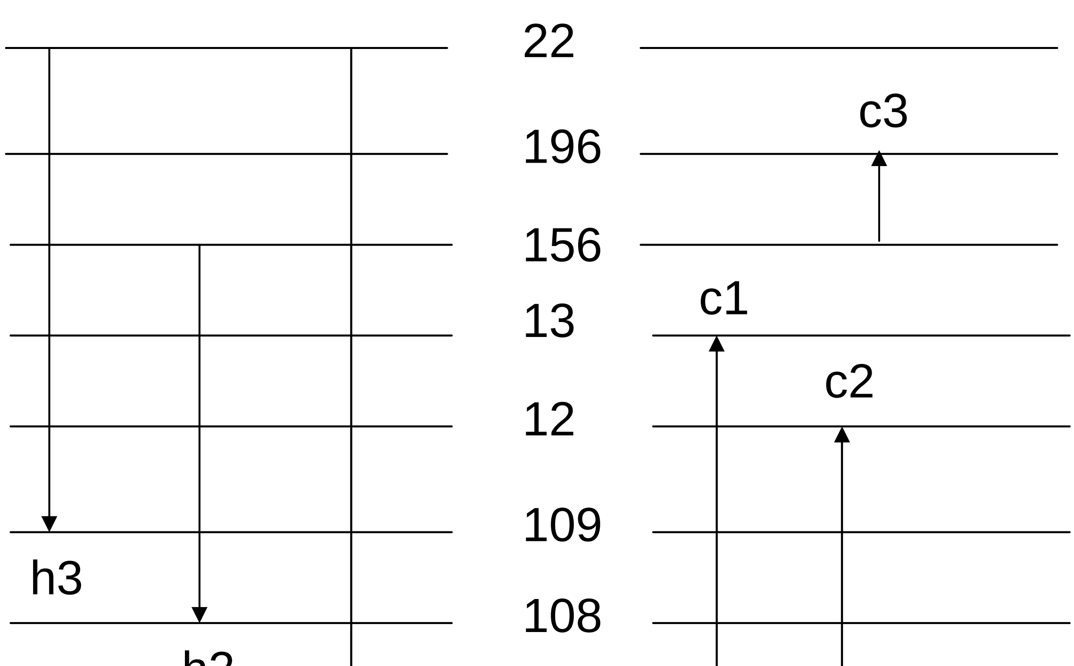
Temperature Interval Method

stream no.	condition	m.Cp	Tin (F)	Tout (F)
1	cold	4893	77	133
2	cold	2173	77	129
3	cold	5.0*10^5	156	196
4	hot	1.23*10^4	244	77
5	hot	2.75*10^5	176	128
6	hot	1046	244	129

the temperature were adjuseted by Δtmin=20F

			Adjueted temperature		
C1	77	133			
			77		T7
				133	T3
C2	77	129			
			77		T7
				129	T4
C3	156	196			
			156		T2
				196	T1
H1	244	77			
			224		To
				57	T8
H2	176	128			
			156		T2
				108	T6
H3	244	129			
			224		To
				109	T5

B3-8

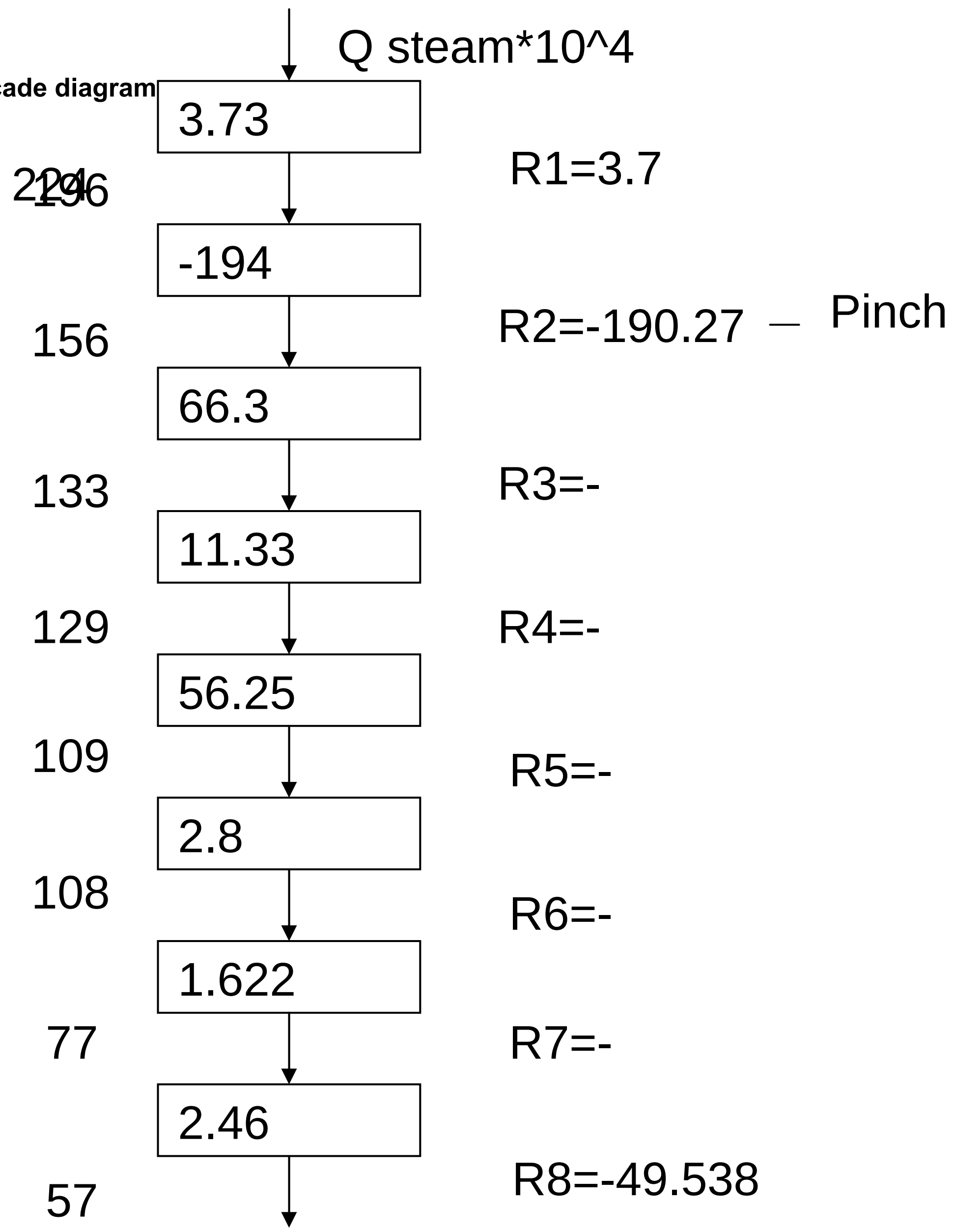


Th heat duty for each interval

Q1=	373688
Q2=	-19466160
Q3=	6631958
Q4=	1133812
Q5=	5625600
Q6=	28303634
Q7=	162254
Q8=	246000

B3-9

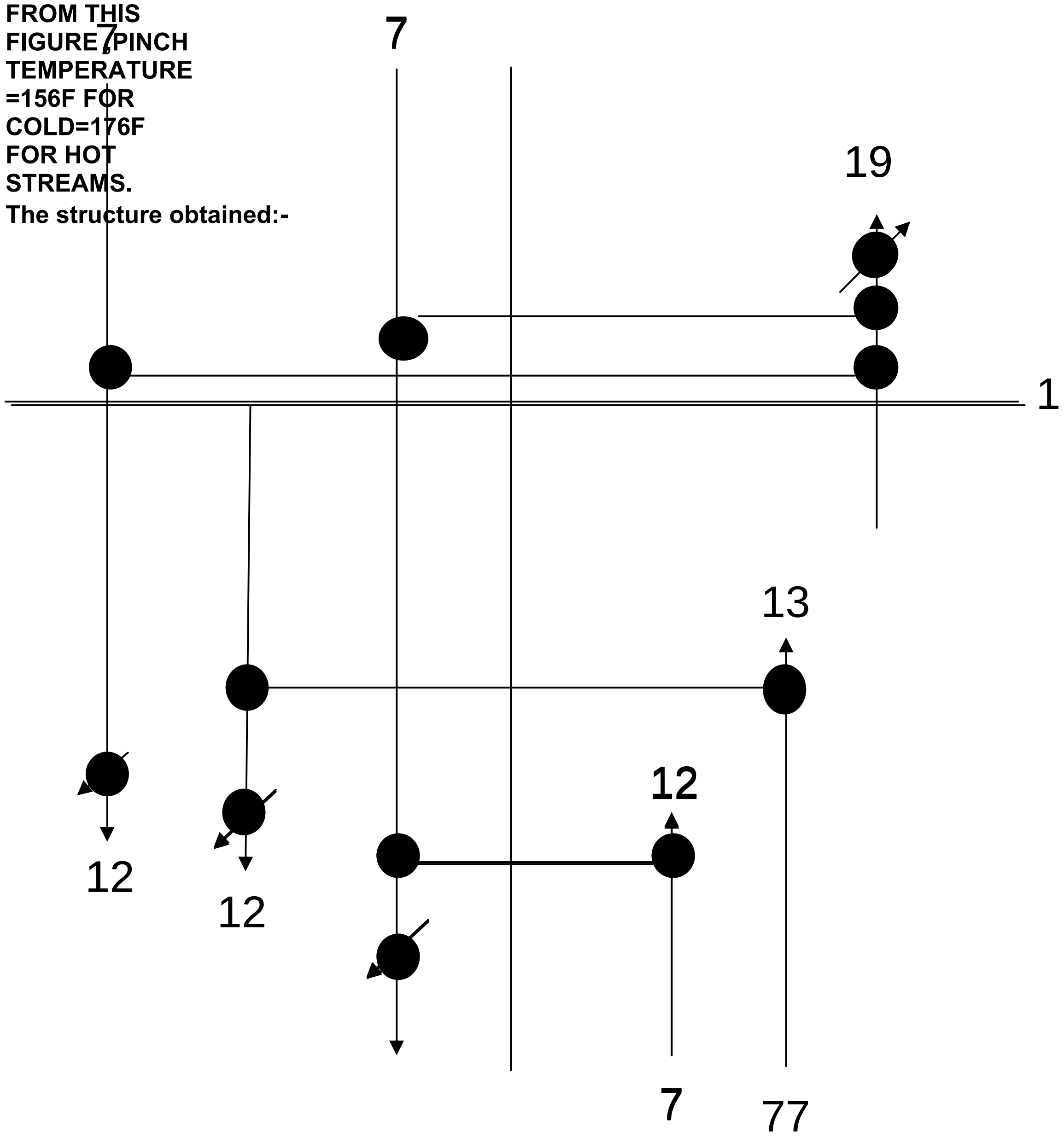
Cascade diagram



B3-10

FROM THIS FIGURE,PINCH TEMPERATURE =156F FOR COLD=176F FOR HOT STREAMS.

The structure obtained:-



B3-11

Calculations fore the network

Above

heat exchanger {1}

Q=	**836400**	**t3=**	**157.67**

ΔTlm=	45.378271	A=	122.87819	C=	6277.012	$/yr
heat exchanger {2}					9415518	ID
Q=	71128	t3=	157.8			
ΔTlm=	43.902832	A=	10.800822	C=	1459.292	$/YR
heater					2188938	ID
Tin=	157.8	Tout=	196			
Tsin=	540	Tsout=	540			
Q=	19100000					
ΔTlm=	362.76485	A=	263.25594	C=	9915.051	$/YR
λ=	656.6	ms=	29089.248		14872576	ID
				Cs=	254821.8	$/YR
Below					3.82E+08	ID
heat exchanger {3}						
Q=	112996	t4=	166.8			
ΔTlm=	66.10678	A=	11.395301	C=	1506.966	$/YR
heat exchanger {4}					2260449	ID
Q=	274008	t4=	175			
ΔTlm=	66.766423	A=	27.35986	C=	2548.804	$/YR
Coolers					3823205	ID
cooler {1}						
Tin=	166.8	Tout=	77			
Twin=	100	Twout=	146.8			
Q=	1104540					
ΔTlm=	21.465071	A=	343.05035			
mw=	23601.282	Cw=	10337.362	$/yr		
			15506042	ID/YR		
		C=	11622.051	$/YR		
			17433076	ID		

cooler {2}				
Tin=	175	Tout=	129	
Twin=	100	Tw out=	155	
Q=	48116			
ΔTlm=	24.221966	A=	13.243076	
mw=	874.83636	Cw=	383.17833	$/YR
			574767.49	ID/YR
		C=	1649.1546	$/YR
			2473731.8	ID/YR
cooler {3}				
Tin=	176	Tout=	128	
Twin=	100	Twout=	156	
Q=	13200000			
ΔTlm=	23.776107	A=	3701.1946	
mw=	235714.29	Cw=	103242.86	$/YR
			154864286	ID/YR
		C=	48425.398	$/YR
			72638097	ID
total cost of heat exchangers=			17688110	

total cost of heaters=			14872576	
total cost of coolers=			92544904	
total cost of steam=			382232714	
total cost of cooling water=			170945096	
J=	377125.58	$/YR	565688369	ID/YR
A=	113247.54	ft^2	10520.696	m^2

الخلاصة

تهتم هذه الدراسة بإنشاء شبكة مبادلات حرارية لاستخدام الطاقة الموجودة في السوائل الحارة لتسخين السوائل الباردة وتقوم مثل هذه العملية بتقليل كلفة اعداد وحدة صناعية مؤلفة من المبادلات الحرارية و بتقليل استخدام مصادر خارجية للتسخين و التبريد مثل البخار الساخن و ماء التبريد.

يتم انتقال الطاقة من المسالك الساخنة الى المسالك الباردة بالاعتماد على عدة عوامل وهي نسبة الجريان لهذه السوائل (كغم/ساعة) ومساحة المبادل الحراري و معامل انتقال الحرارة ومستوى الحرارة على طول المساك.

ان اعداد شبكة مبادلات حرارية تم على اساس نظرية الطور الواحد للمسالك عند دخولها للمبادل الحراري وبعد خروجها منه وبهذا تبقى قيمة السعة الحرارية ثابتة وقد طبقت هذه النظرية على ثلاث انظمة سائلة وهي النظام (أ) الذي يتألف من اربعة مسالك (اثنان ساخنان واثنان باردان) و النظامان (ب) و (ج) المؤلفان من ستة مسالك (ثلاثة ساخنة وثلاثة باردة). وقد اختيرت قيمة 11^{o}س كأقل درجة حرارة تقارب للمبادل الحراري وذلك لانها الانسب للمبادل الحراري الذي تم اختياره لتصميم الشبكة واذا ما تم اختيار قيمة اعلى او اوطأ فأن كلفة الشبكة ستتأثر بتغيير تلك القيمة.

ان عمل شبكة مبادلات حرارية للأنظمة الثلاث المختارة تم أولا عن طريق النظريات التي هي عباره عن قوانين للربط بين المسالك الحارة والباردة وهي ثلاث

نظريات هذه النظريات قد طبقت على النظام الاول (أ) بحيث اعطت النظريه الاولـى اربعة احتمالات وكان اقلها كلفة هو الاحتمال الثاني مما يجعله الافضل من حيث الكلفة والتي كانت تساوي $3,65\times10^{6}$ دينار عراقي /سنة واعطت النظريـة الثانيـة ثمانيـة احتمالات كانت الاقل كلفة بينها الاحتمالية الرابعة والتي كانت كلفتها ايـضا $3,65\times10^{6}$ دينار عراقي/سنة، بينما اعطت النظرية الثالثة شبكة واحدة وبكلفة 113×10^{6} دينـار عراقي/سنة. بناءا على هذه النتائج وجد ان النظرية الاولى هي الافضل لهـذا النظـام لانها اعطت الشبكة الاقل كلفة بطريقة مختصرة.

في النظام الثاني (ب) عند تطبيق النظرية الاولى حصلنا على خمس احتمالات ، الثالثة كانت الاقل كلفة بينها حيث كانت كلفتها= 107×10^{6} دينار عراقي/سـنة. بينمـا اعطت النظرية الثانية 25 احتمالية للربط وكانت الاحتمالية الاولى هـي الاقـل كلفـة وبكلفة 58.1×10^{6} دينار عراقي /سنه.

الشبكة المحصل عليها من النظريه الثالثة كانـت كلفتهـا= 60.8×10^{6} دينـار عراقي/سنة وكانت هذه القيمة قريبه جدا من الشبكه الاقل كلفة المحـصل عليهـا مـن النظرية الثانية لنفس النظام.

ثم طبقت النظرية الثانية وهي طريقة الفترات الحرارية على النظـامين (ا) و (ج) حيث حصلنا على شبكة واحدة لكل نظام. كانت كلفة شبكة النظام (ا) =47.5×10^{6} دينار عراقي/سنة وكانت كلفةالنظام (ج)=567×10^{6} دينار عراقي/سنة. بعدها طبقت الطريقة الثالثة على نفس الانظمة (ا) و (ج) حيث اعطت نفس النتائج ونفـس الكلفـة المحصل عليها من طريقة الفترات الحرارية.

لكي نثبت ان تغيير درجة حرارة التقارب من 11 الى 5,5 درجة يؤثر على قيمة الكلفة، طبقت هذه القيمة على النظام(ج) بالطريقة الثالثة ولوحظ ان الكلفة التي حصل عليها في هذه الحالة هي 100×10^{6} دينار عراقي/سنة ، بينما هي 560×10^{6} دينار عراقي/سنة قبل تغيير القيمة.

اذا قارنا نتائج هذا العمل مع اعمال سابقة استخدمت نفس الانظمة و نفس الطرق وجد ان هناك فرق كبير في الحسابات الخاصة بالكلفة يقارب 46% مثلا الشبكة الاقل كلفه في النظام الاول باستخدام النظرية الثانية كانت كلفتها 60.9×10^{6} دينار عراقي/سنة في سنة 1975 وفي العمل الحالي اصبحت القيمة لنفس الشبكة 113×10^{6} دينار عراقي/سنة بعد تصحيح قيمة المصادر الخارجية للتسخين و التبريد (البخار و الماء الخاص بالتبريد) ونظرا لأرتفاع كلفة مواد التصنيع.

شكر و تقدير

اود ان اعبر عن شكري وتقديري و امتناني العميق للمشرفة الدكتورة ندى بهجت النقاش لما قدمته لي من توجيهات و نصائح قيمة ومـساعدة كبيرة في اتمام هذا البحث.

اود ايضا ان اشكر رئاسة قسم الهندسة الكيمياوية بكامل كادره مـن اساتذة و منتسبين للمساعدة في انجاز هذا العمل.

ولا انسى ان اشكر والداي وعائلتي العزيزه وكل من ساندني على صبرهم وتفهمهم خلال فترة دراسـتي. شـكر خـاص الـى زوجـي العزيزعلى تعاونه الكبير وصبره الجميل.

شبكات المبادلات ألحرارية

رسالة
مقدمة الى كلية الهندسة في جامعة النهرين وهي جزء
من متطلبات نيل درجة ماجستير علوم في
الهندسة الكيمياوية

من قبل
ختام علوان عباس

(بكالوريوس علوم في الهندسةالكيمياوية 2003)

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