بسم الله الرحمن الرحيم

Sudan University of science and Technology

College of graduate studies

Energy benchmarking of steam thermal power station By using pinch analysis (case study: kosti thermal power station)

معيار الطاقة لمحطات القدرة البخارية باستخدام تقنية التقليص في التحليل (دراسة حالة:محطة توليد كهرباء كوستي الحرارية)

Thesis Submitted in Partial Fulfillment of the Degree of M.Sc. in Mechanical Engineering (POWER)

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AUGUST 2018

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الآية

بسم الله الرحمن الرحيم

قال تعالى:

﴿يرفع الله الذين آمنوا منكم والذين أوتوا العلم درجات﴾

(سورة المجادلة الآية **١١**)

Dedication

To my father how gives me direction to the sky

To my mother how gives me lovely life

To my brothers and sisters how gives me support

To my wife who gives me wormed life

To my friend's Eng.: Mohamed abd-elwhab &Eng.:

ekrema solumanhow gives me support

Acknowledgement

First of all I would like to submit my best greeting to my supervisor **Dr. Abuelnuor Abdeain** for his acceptance to supervise my research and for his directions during preparing this research. Also my full respect and appreciation to all friends, colleagues and co-worker enhanced me in this research and helped me in data collection stage

I also acknowledge all those who contributed, in any way, to make this work possible.

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Abstract

The rising cost of energy and environmental concerns have led the power plant to search for techniques of reducing energy consumption in thermal operations. In this research, pinch analysis was applied to steam thermal power station (case study: kosti thermal power station) to target for the energy requirements of the process. The objective of this study is to apply pinch technology for optimizing the performance of plant because Pinch technology presents a simple methodology for systematically analyzing for Power Plant Processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics.

From the Pinch analysis performed, the Composite Curves revealed that, at a minimum temperature difference of 10°C, the minimum cooling and heating utility requirements of the plant studied were determined as being 185.7 KW and 53050.3 KW respectively, with a pinch temperature at 47˚C. It was observed that using the technique 141538.7KW of energy could be recovered through process to process heat exchange. It is recommended that results from this study could be used in the design or retrofit of a heat exchanger network of the plant for improved energy efficiency. Considerations can also be made for other values of ΔTmin.

تجريدة

ادى ارتفاع تكلفة الطاقة والمخاوف البيئية إلى قيام محطات الطاقة بالبحث عن تقنيات لتقليل استهلاك الطاقة في العمليات الحرارية. في هذا البحث ، تم تطبيق التحليل على محطات الطاقة الحرارية البخارية (دراسة حالة: محطة كوستي الحرارية البخارية) لاستهداف متطلبات الطاقة للعملية.الهدف من هذه الدراسة هو تطبيق تقنية التقليص لتحسين الأداء لأن تقنية التقليص تقدم منهجية بسيطة للتحليل المنهجي لعمليات محطات توليد الطاقة وأنظمة المرافق المحيطة بمساعدة القانون الأول والثاني للديناميكا الحرارية.

من التحليل الذي تم إجراؤه ، كشفت المنحنيات المركبة أنه عند الحد الأدنى لدرجة الحرارة عند 10 درجة مئوية ، تم تحديد الحد الأدنى لمتطلبات التبريد والتدفئة للمحطة على أنها 185.7 كيلو واط و 53050.3 كيلوواط على التوالي ، مع درجة حرارة تقليص عند ٤٧ درجة مئوية. وقد لوحظ أن باستخدام التقنية يمكن استرداد 141538.7 كيلوواط من خلال عملية التبادل الحراري.عليه يوصى باستخدام نتائج هذه الدراسة في تصميم أو إعادة تهيئة شبكة المبادلات الحرارية في المحطة لتحسين كفاءة الطاقة، كما يمكن أيضًا إجراء اعتبارات اخري لقيم فروقات الحرارة الدنيا.

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HEN	heat exchanger network
MTD	minimum temperature difference
SEC	specific energy consumption
QA	quality assurance
DEA	data envelopment analysis
OLS	Ordinary Least Square
DAS	Data Acquisition System
DM	Demean Plant
DMCW	Demean Plant Closed circuit
ACW	Auxiliary Cooling System
SH	Superheater
RH	Reheater
APH	Air Preheater
FD	Force Drafty
GR	Gas Recirculation
ERV	Electrometric relief valve
PFD	process flow diagram
MAT	Minimum approach temperature
CP	Heat Capacity
GCC	Grand Composite Curve
CCGT	combined cycle gas turbine

CHAPTER I

Introduction

CHAPTER I

Introduction

1-1 Introduction

Benchmarking of process industries with respect to energy consumption has always been a challenging issue for effective management of energy resources. Having developed a precise model for estimating the energy consumption; we have a powerful tool to measure and identify the opportunities for improvements through a plant [1]. In this study, a mathematical conceptual model is presented for one-way benchmarking of thermal power plants using Pinch concepts.

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, ahead of design, the minimum requirements of external energy, network area, and the number of units for a given process at the pinch point. Next a heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy cost 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) [2].

1-2 Problem Statement:

-The mean research problem is that there is a large amount of demon water Processed Chemically by adding high-cost chemical material. This demon water non-independent in the process of heat exchange in the heaters area, which appears in the form of over flow water in the cooling towers and goes directly to the drains discharge without independence, which increases the total losses in the plant and thus adversely affects the efficiency of the plant.

- To evaluate the overall performance of the plant and compare its performance to what is designed.
- To evaluating the products, services, and work processes of organizations that are recognized as representing best practices, for the Purpose of organizational improvement.

1-3 Research Objectives

1. To reduce losses and enhance operating capacity.
2. To Improving energy efficiency by analyzing energy use is an important step toward reducing greenhouse gas emissions and energy consumption.
3. to using in company for comparing of performance and energy-saving.

CHAPTER II

Literature Review

CHAPTER II

Literature Review

2-1 Literature review

Energy consumption is increased by such factors as population increment, urbanization, industrialization, and technological. The abovementioned growing trend creates critical environmental problems including contamination and greenhouse effect. One of the most distinctive indicator showing the development stages of countries and living standards of communities is “energy consumption per capita”. Efficient energy use, as the aim to decrease the amount of energy required to provide products and services without even reducing the quality of final products and services, is one of the energy efficiency level indicators .Two approaches are used to acquire the efficient processes: the first is the construction of new plants with new technologies and energy efficient processes, and the second is to retrofit the existing plants with respect to new energy consuming standards.

The first approach is not economical and requires a notable finance resources and new licenses, while the second approach is applicable and appealing to industrialists.

That is why the researchers decrease the energy costs in existing plants through energy management practices. To be strong enough in competitive market and maintain profit margin, it is necessary to have a complete overview of plant and be aware of its strengths and weakness. Benchmarking specifies the reference points and as a tool, helps companies observe the desired industry and compare the performance of their own plant with the best practice of that industry. Knowing the gap between the existing plant and the best practice helps managers setup a comprehensive program about energy-saving projects and make decision regarding investment and payback period. Approximately 80% of world electricity demand is produced from fossil fuels (coal, petroleum, fuel-oil, natural gas) in fired thermal power plants, while the remaining 20% is supplied by hydraulic, nuclear, wind, solar, geothermal and biogas sources. Power sector is highly energy-intensive, drawing the attention of researchers worldwide due to technical problems. Nevertheless, power sector retrofit has begun in many countries for three decades. This study is aimed at benchmarking the functional parameters of steam cycle power plants and significant parameters in targeting the energy-area for the retrofit of conventional steam cycle power plants based on Pinch Analysis [1].

The benchmarking method has been used to evaluate the energy efficiency performance of industry for several years. It is used as an energy efficiency instrument itself, but more frequently it is included in energy efficiency programs which consist of several instruments. The combination of different policy instruments also gives the best results in order to reach energy efficiency objectives for industry .The indicator used more often for benchmarking industry is specific energy consumption (SEC), which is measured in KW/H per production volumes.

Usually the SEC is based on actual energy consumption and production volumes from manufacturing companies within a certain industry. Mainly two different approaches have been used to calculate and set up the benchmarks for evaluation: calculation of the arithmetic average or other reference values of a target group.

Benchmarking is a tool for improving performance. Benchmarking defines as a continuous and systematic process of comparing products, services, processes and outcomes with other organizations or exemplars, for the purpose of improving outcomes by identifying, adapting and implementing best practice approaches Comparisons may be made against individual benchmarking partners or groups; other programs sets of accepted standards; or data from past performance . Benchmarking is different to using quality assurance (QA) models, as QA models generally focus on minimum acceptable standards and compliance and they are often imposed by management or external inspection requirements.

There are many types of benchmarking and many ways of categorizing these types. Some terms are used by different authors with different meanings. Each type seems useful for a particular situation. However, the type of benchmarking is not as important as that the aims are clear, achievable and achieved, and that the choice of partner organization is aligned with the aims [4].

2-2 Principles of Benchmarking

Ten principles form benchmarking theory:

1. Improves practices, services or products.
2. Involves learning about ‘best practices’ from others.
3. accelerates the rate of progress and improvements.
4. Contributes to continuous quality management.
5. Is an ongoing process.
6. Promotes fresh and innovative thinking about problems.
7. Provides hard data on performance.
8. Focuses not only on what is achieved, but on how it is achieved.
9. Involves the adaptation, not merely adoption, of best practices; and
10. Results in the setting of specific targets.

2-3 Why Benchmark? – Benefits

Why should higher education organizations care about benchmarking? In a word: competition. In the past, it may have been possible to identify friendly rivals but recently the competitive landscape is changing quickly with new, non-traditional rivals that may be overlooked as competitors or benchmarking.

One of the most important benefits of benchmarking is the discovery of innovative approaches. Benchmarking highlights problem areas and the potential for improvement, providing an incentive to change, and assists in setting targets and formulating plans and strategies. Benchmarking provides assessments of quality that identify measures that give a valid and balanced current picture of the parameters that distinguish courses, universities or sections of a university.

As a result of good benchmarking university leaders would know how their institution rates in certain areas in comparison with others, ascertain their competitive position relative to others, and also know how their institution can be improved. Benchmarking may enable an institution to lay a legitimate claim to being “distinguished” in a particular area. The findings from benchmarking enable universities to priorities resources and use their resources to best effect. Benchmarking can ensure that plans are being carried out and demonstrate areas of merit to stakeholders. Yet benchmarking distinguishes between real innovation and simple reputation as it focuses on demonstrating best practices beyond their initial launch.

To maximize the benefits of benchmarking, institutions must undergo a thorough self-analysis and have a clear understanding of their own processes which may be more useful than the comparison with another organization. Beyond the potentially humbling learning experience of benchmarking, the networking creates opportunities for further collaboration [3].

2-4 Benchmarking Concepts and Methods

Benchmarking is a process that allows the companies to assess the status of plants compared to others. It means that to recognize the place of a company in an industry, it is necessary to compare its substantial function with those of others. In this comparison process, the last achievements of others can be recognized and the best one chosen. It is a good practice that shows the path of development to leaders and also specifies what must be done to improve.

Benchmarking acts as a function, which receives some input variables, compares these inputs with a base case and gives a number of outputs. Inputs are the information that shall be received from inspection of plants. Comparing the inputs is the process of comparing the main characteristics of desired plant with the other one or may be the best practice, and the output is the map of road for development.

There is a variety of benchmarking methods and procedures based on the nature of industry or organization and available data. Based on a classification, actual performance of an organization can be compared with the performance of all existing samples. This method is usually time consuming and costly. Also there is more conventional kind of benchmarking that can be defined according to base case specific property. This unique property can be divided into two categories. The first one, called “best (frontier)”, is about a sample or reference that is the best one in a statistical society. The second one that is more applied is known as “mean (average)”, that is an average performance of statistical society.

2-4-1 Frontier benchmarking methods

Frontier benchmarking methods are usually used for targeting specific efficiency Requirements. This approach can be applicable at the initial stages of organization when the priority objective is to reduce the performance gap among the firms.

The frontier-based benchmarking methods propose an applicable performance goal resulting from the best practice in an industry or a host of firms.

The commonly used mathematical method for this approach is data envelopment analysis (DEA). In DEA, according to performance of each sample, a score is allocated to each sample, which is indicative of the ranking of that sample among other firms. An advantage of this method is that there is no need to define a particular production or cost function. This method can be applied to both general and technical efficiency functions. The effect of each internal/ external or environmental item can be detected in this method.

In DEA method, results of benchmarking might be sensitive to model inputs and outputs, because DEA method utilizes a limited amount of available information as reference data, specifically best practices, to deduct the efficiency scores.

2-4-2 mean and average benchmarking

Average benchmarking method is usually used when no egregious difference exists between firms. This method is used for approximation of firms’ efficiencies in a general progress that is done by a regulator. Unlike frontier methods, benchmarking can be in relation to average performance of firms as the reference point. One simple mathematical method for mean benchmarking is Ordinary Least Square (OLS) method that is a regression based on statistical data of an industry. A study for estimation the relationship between energy consumption, economic growth and CO2 emission in China over the period 1970-2015 has been carried out using OLS method. A fully modified OLS has been applied to explore the relationship between greenhouse gas, financial development and energy consumption in 34 countries from Asia, Europe, Africa and America using data from 2001 to 2014.

2-5 Steps of benchmarking

Three step processes for benchmarking involves:

1. Identifying areas for improvement.

2. Choosing benchmark indicators (quantitative measures of achievement). And then,

3. Collecting information to enable comparisons in order to improve performance.

Benchmarking process has four phases:

- Planning.
- Analysis.
- Integration, and
- Action.

1. Planning have five steps:

- Determine what to benchmark,
- Identify key performance indicators,
- Identify benchmarking partners,
- Determine data collection method, and.
- Collect data.

2. Analysis has two steps:

- Understand performance gaps, and
- Predict future performance levels.

3. Integration has two steps:

- Communicate findings and gain acceptance, then
- Establish functional goals and implementation plans; and.

4. Action has three steps:

- Implement and monitor progress.
- Measure results against stakeholder wants and needs, and then- Recalibrate benchmarks. [5]

CHAPTER III

Design Methodology

CHAPTER III

Design Methodology

3-1 Methodology

In recent years a new technology for minimizing the energy requirements of process plants has been developed: this has been named Pinch Technology or Process Integration by its Major proponent, (Linnhoff and Senior, 1983; Linnhoff and Turner 1981). Process plants, such as oil refineries or major chemical manufacturing plants, require that heating and cooling of the feed stock take place as the processes occur. Obviously it would be beneficial to use the energy from a stream which requires cooling to heat another which requires heating; in this way the energy that has to be supplied from a high temperature Source (or utility) is reduced, and the energy that has to be rejected to a low temperature sink (or utility) is also minimized. Both of these external transfers incur a cost in running the plant. Pinch technology is an approach which provides a mechanism for automating the Design process, and minimizing the external heat transfers. Pinch situations also occur in power generation plant; for example, in a combined cycle gas turbine (CCGT) plant (see Fig 3.1) energy has to be transferee from the gas turbine exhaust to the working fluid in the steam turbine. A T-s diagram of a CCGT plant is shown in Fig (3.2), where the heat transfer region is shown: the pinch is the closest approach in temperature between the two lines. It is defined as the minimum temperature difference between the two streams for effective heat transfer, and is due to the difference in the properties of the working fluids during the heat transfer process (namely, the exhaust gas from the gas turbine cools down as a single phase but the water changes phase when it is heated) - this limits the amount of energy that can be taken from the hot fluid. The heat transfer processes are shown on a temperature-enthalpy transfer diagram in Fig (3.3), where the pinch is obvious [12].

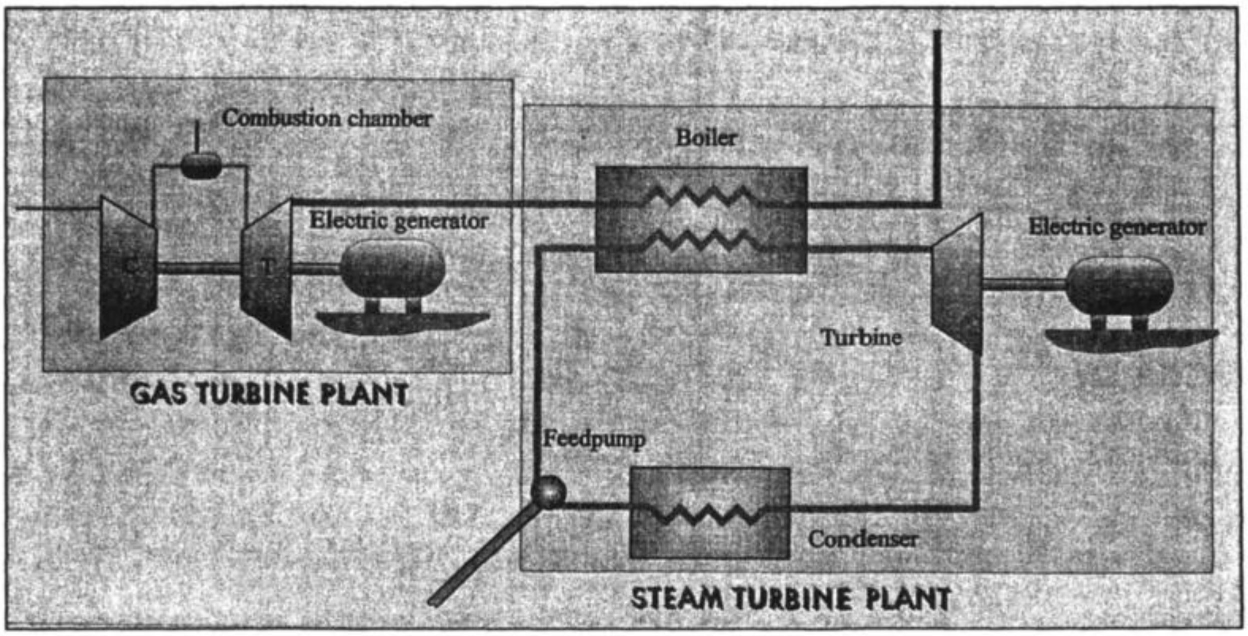


Figure (3-1) combined cycle gas turbine

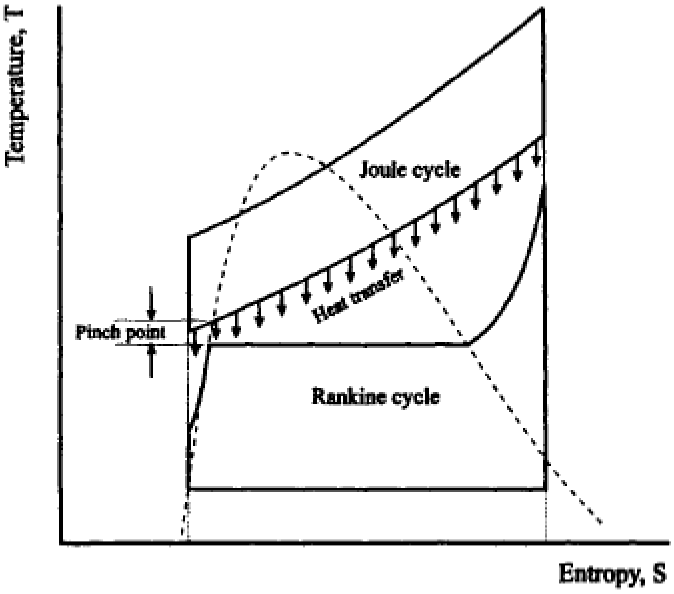


Figure (3-2) energy transferee from gas turbine exhaust to the working fluid in the steam turbine

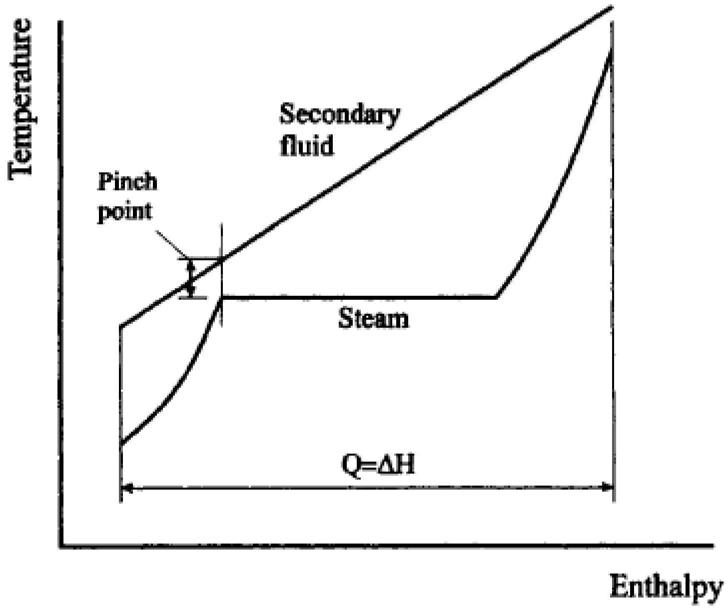


Figure (3-3) temperature-enthalpy transfer diagram

3-2 Pinch approach:

The general pinch approach is shown in figure (3-4) below. The complex multi-dimensional problem is first transposed into the pinch format, which plots simplified “composite curves” of resource (energy, water, etc.) demand and availability. Then targets are set, and a broad set of pinch design rules are used to create a design that approaches the targets as closely as economically and practically possible. Working in this transposed environment gives the engineer a simple visualization of even the most complex problems and enables quick assessment of alternatives, including outline economics.

Constraints can easily be considered and either overcome or accepted.

Finally, the pinch environment is transposed back to process flow diagram (PFD) form, and the conventional steps of simulation, feasibility checking and detailed design are completed [6].

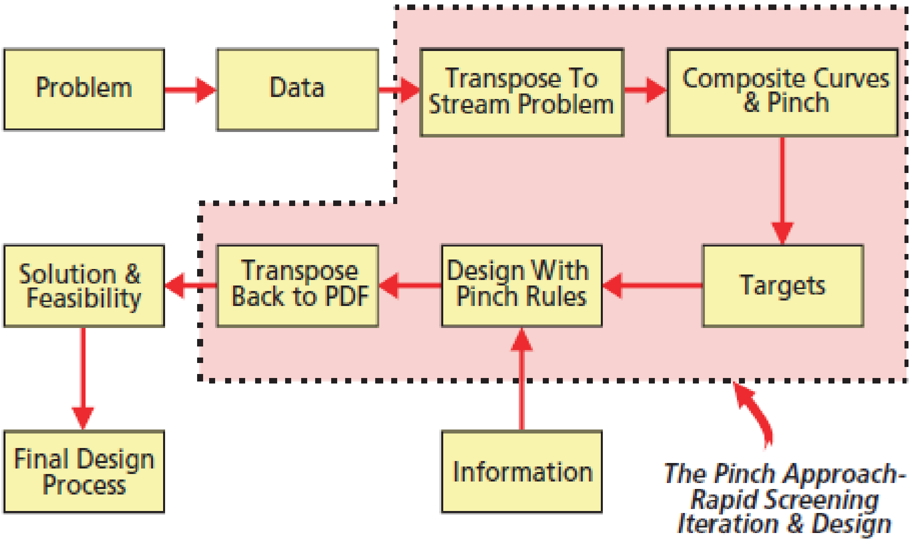


Figure (3-4) the general pinch approach

3-3 Key concepts of pinch analysis

In this section, we will present the key concepts of pinch analysis, showing how it is possible to set energy targets and achieve them with a network of heat exchangers.

These concepts will then be expanded for a wide variety of practical situations in the following chapters.

3-3-1 Heat recovery and heat exchange

Basic concepts of heat exchange:

Consider the simple process shown in figure (3-5) below. Liquid is supplied to the reactor and needs to be heated from near-ambient temperature to the operating temperature of the reactor. Conversely, a hot liquid product from the separation system needs to be cooled down to a lower temperature. There is also an additional unheated make-up stream to the reactor.

Any flow which requires to be heated or cooled, but does not change in composition, is defined as a stream. The feed, which starts cold and needs to be heated up, is known as a cold stream. Conversely, the hot product which must be cooled down is called a hot stream. Conversely, the reaction process is not a stream, because it involves a change in chemical composition; and the make-up flow is not a stream, because it is not heated or cooled.

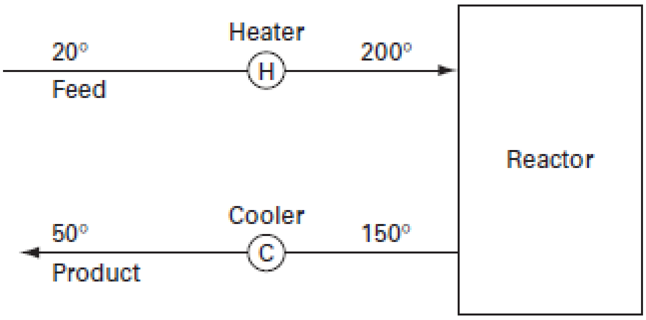


Figure (3-5) simple process flow sheet

To perform the heating and cooling, a steam heater could be placed on the cold Stream, and a water cooler on the hot stream.

Can we reduce energy consumption? Yes; if we can recover some heat from the hot stream and use it to heat the cold stream in a heat exchanger, we will need less steam and water to satisfy the remaining duties. The flow sheet will then be as in figure (3-6).

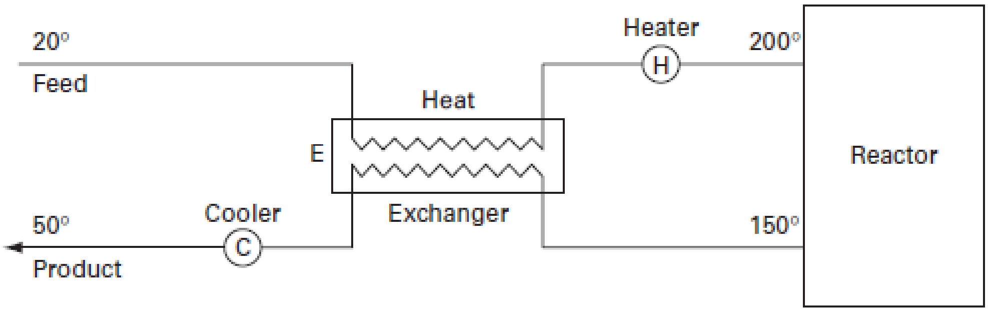


Figure (3-6) simple process flow sheet with heat exchanger

3.3.2 The temperature- enthalpy diagram

A helpful method of visualization is the temperature–heat content diagram, as illustrated in figure (3-7).

The total heat added will be equal to the stream enthalpy change, i.e.

$$Q = \int_{T_S}^{T_T} CP\,\mathrm{d}T = CP(T_T - T_S) = \Delta H$$

(3-1)

Where:

CP= “heat capacity flow rate” (kW/K) = mass flow *W* (kg/s) x specific heat *C*P (KJ/kgK)

d*T* = differential temperature change Hence, with *CP* assumed constant, for a stream requiring heating (“cold” stream) from a “supply temperature” (*T*S) to a “target temperature” (*T*T),

The heat content *H* of a stream (kW) is frequently called its enthalpy; this should not be confused with the thermodynamic term, specific Enthalpy (kJ/kg). Differential heat flow d*Q*, when added to a process stream, will Increase its enthalpy (*H*) by *CP* d*T*,

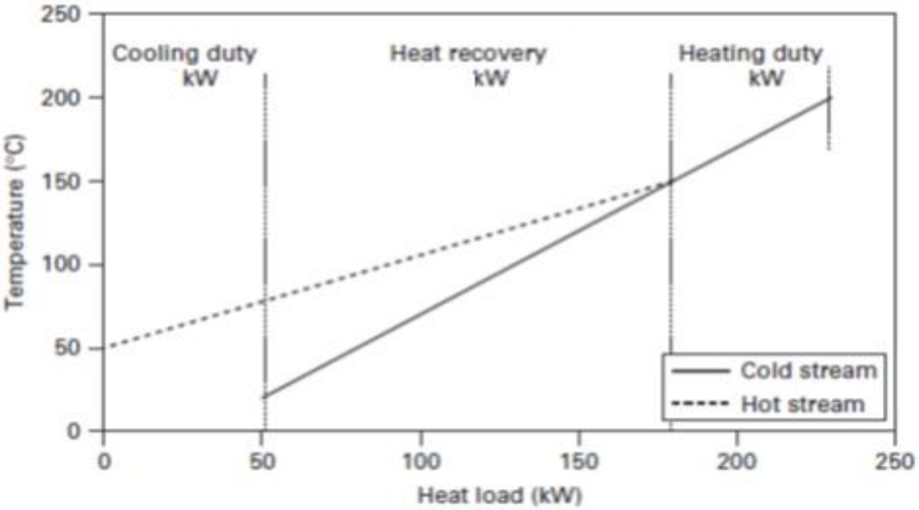


Figure (3-7) streams plotted on temperature/ enthalpy diagram with $\Delta T\mathrm{min} = 0$

And the slope of the line representing the stream is:

$$\frac{dT}{dQ} = \frac{1}{CP} \qquad (3.2\ )$$

The *T*/*H* diagram can be used to represent heat exchange, because of a very useful feature. Namely, since we are only interested in enthalpy changes of streams,

A given stream can be plotted anywhere on the enthalpy axis. Provided it has the same slope and runs between the same supply and target temperatures, then wherever it is drawn on the H-axis, it represents the same stream.

The figure (3-8) shows the hot and cold streams plotted on the *T*/*H* diagram. Note that the hot stream is represented by the line with the arrowhead pointing to the left, and the cold stream vice versa. For feasible heat exchange between the two, the hot stream must at all points be hotter than the cold stream so it should be plotted above the cold stream**.**

The cold stream is shown shifted on the H-axis relative to the hot stream so that the minimum temperature difference, Δ*T*min is no longer zero, but positive and finite. The effect of this shift is to increase the utility heating and cooling by equal amounts and reduce the load on the exchanger by the same amount. This arrangement is now practical because the ΔTmin is non-zero. Clearly, further shifting implies larger ΔTmin values and larger utility consumptions.

From this analysis, two basic facts emerge. Firstly, there is a correlation between the value of ΔTmin in the exchanger and the total utility load on the system. This means that if we choose a value of ΔTmin, we have an energy target for how much heating and cooling we should be using if we design our heat exchanger correctly.

Secondly, if the hot utility load is increased by any value α, the cold utility is increased by α as well. More in, more out! As the stream heat loads are constant, this also means that the heat exchanged falls by α [8].

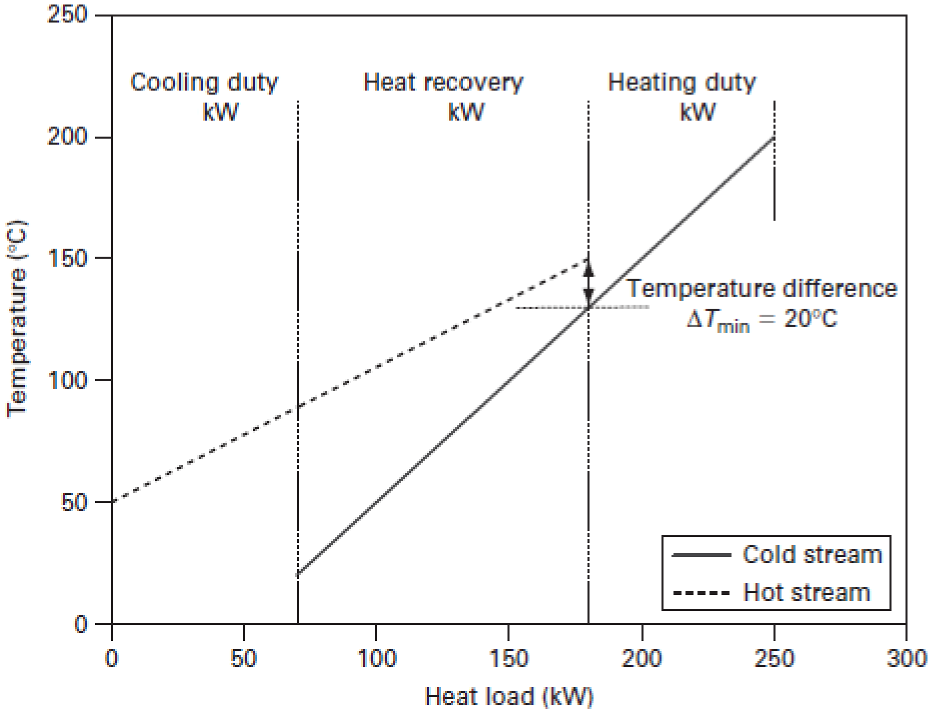


Figure (3-8) streams plotted on temperature/ enthalpy diagram with $\Delta T\mathrm{min} > 0$

3.3.3 Thermal Energy Efficiency and Design of Heat Exchanger Networks

All manufacturing processes require energy in the form of heat and power. Power is consumed both for shaft work (to drive industrial machinery) and for process cooling.

The individual process heating duties can be combined into a single “cold composite curve” drawn on a temperature enthalpy (T-H) diagram; it represents the enthalpy demand profile of the process. Similarly, all the cooling duties can be combined into a single “hot composite curve,” which represents the enthalpy availability profile of the process.

When both curves are plotted on the same T-H diagram, as in figure (3-9). They show the opportunity for heat recovery as well as the minimum net heating and cooling requirements.

The point of closest approach, where available temperature driving forces between hot and cold streams are at a minimum, is called the process pinch. It separates the overall Process into two distinct thermal domains:

- A net heat sink above the cold pinch temperature, meaning that hot utility must be supplied.
- A net heat source below the hot pinch temperature, meaning that cooling must be provided.

The temperature difference between hot and cold streams at the pinch is called the minimum approach temperature (MAT). For each value of MAT, there are corresponding values of minimum heating and cooling requirements (Qh) min and (Qc) min. These are the energy targets [6].

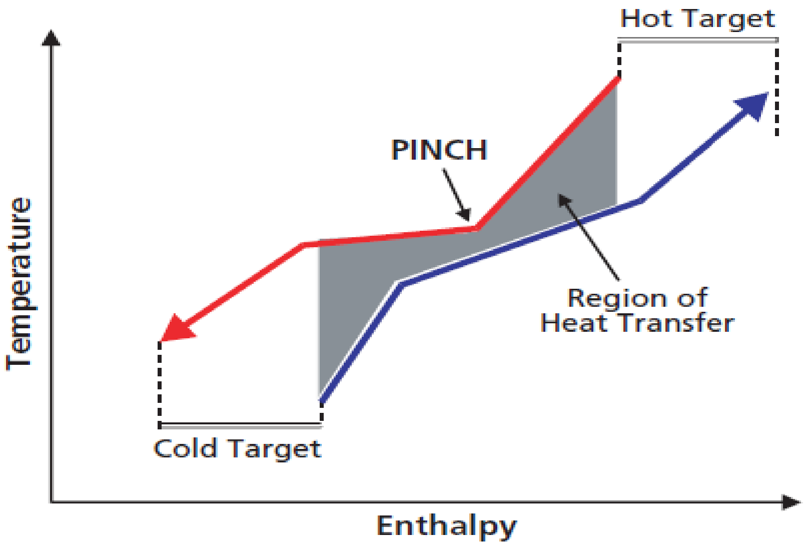


Figure (3-9) heat recovery as well as the minimum net heating and cooling requirements.

3.4 steps of pinch analysis

1. Identification of Hot, Cold and Utility Stream in Process.
2. Thermal Data Extraction for Process and utility stream.
3. Construction of Composite and Grand Composite curve.
4. Estimation of minimum energy cost target.
5. Estimation of HEN Capital cost target.
6. Estimation of optimum DTmin Value.
7. Estimation of practical target for HEN design.
8. Design of HEN.

3-4-1 Identification of Hot, Cold and Utility Stream in Process

a. Hot Streams:

Are those that must be cooled or are available to be cooled? E.g. product cooling before storage.

b. Cold Streams:

Are those that must be heated e.g. feed preheat before a reactor.

c. Utility Streams:

Are used to heat or cool process streams, when heat exchange between process streams is not practical or economic. A number of different hot utilities (steam, hot water, flue gas, etc.) and cold utilities (cooling water, air, refrigerant, etc.) are used in industry

The identification of streams needs to be done with care as sometimes, despite undergoing changes in temperature, the stream is not available for heat exchange. For example, when a gas stream is compressed the stream temperature rises because of the conversion of mechanical energy into heat and not by any fluid to fluid heat exchange. Hence such a stream may not be available to take part in any heat exchange. In the context of pinch analysis, this stream may or may not be considered to be a process stream.

3-4-2 Thermal Data Extraction for Process & Utility Streams

For each hot, cold and utility stream identified, the following thermal data is extracted from the process material and heat balance flow sheet:

a. Supply temperature (TS °C).

The temperature at which the stream is available.

b. Target temperature (TT °C).

The temperature of the stream must be taken to.

c. Heat capacity flow rate (CP kW/°C)

The product of flow rate (m) in kg/sec and specific heat (Cp kJ/kg °C).

$$\mathbf{CP} = \mathbf{m} \times \mathbf{Cp} \tag{3.3}$$

d. Enthalpy Change (H).

Associated with a stream passing through the exchanger is given by the First Law of Thermodynamics:

$$H = Q \pm W \tag{3.4}$$

In a heat exchanger, no mechanical work is being performed**:**

$$W = 0 \text{ (zero)}$$

The above equation simplifies to

$$H = Q \tag{3.5}$$

Then:

$$Q = CP \times (TS - TT) \tag{3.6}$$

Enthalpy Change:

$$H = CP \times (TS - T\,T) \tag{3.7}$$

The stream data and their potential effect on the conclusions of a pinch analysis should be considered during all steps of the analysis. Any erroneous or incorrect data can lead to false conclusions. In order to avoid mistakes, the data extraction is based on certain qualified principles [7].

3-4-3 Construction of Composite and Grand Composite curve

a. Composite curves:

Temperature - Enthalpy (T - H) plots known as Composite curves’ have been used for many years to set energy targets ahead of design. Composite curves consist of temperature (T) - enthalpy (H) profiles of heat availability in the process (the hot composite curve) and heat demands in the process (the cold composite curve) together in a graphical representation. In general any stream

With a constant heat capacity (CP) value is represented on a T – H diagram by a Straight line running from stream supply temperature to stream target temperature. When there are a number of hot and cold streams, the construction of hot and cold composite curves simply involves the addition of the enthalpy changes of the streams in the respective temperature intervals.

To handle multiple streams, we add together the heat loads or heat capacity flow rates of all streams existing over any given temperature range. Thus, a single composite of all hot streams and a single composite of all cold streams can be produced in the T/H diagram, and handled in just the same way as the two-stream problem.

In fig (3-10.a) below three hot streams are plotted separately, with their supply and target temperatures defining a series of “interval” temperatures T1–T5. Between T1 and T2, only stream B exists, and so the heat available in this interval is given by CPB (T1- T2). However between T2 and T3 all three streams exist and so the heat available in this interval is (CPA + CPB + CPC) (T2 -T1). A series of values of ΔH for each interval can be obtained in this way, and the result re-plotted against the interval temperatures as shown in fig below (3-10.b).

The resulting T/H plot is a single curve representing all the hot streams, known as the hot composite curve. A similar procedure gives a cold composite curve of all the cold streams in a problem.

The overlap between the composite curves represents the maximum amount of heat recovery possible within the process. The “overshoot” at the bottom of the hot composite represents the minimum amount of external cooling required and the “overshoot” at the top of the cold composite represents the minimum amount of external heating**.**

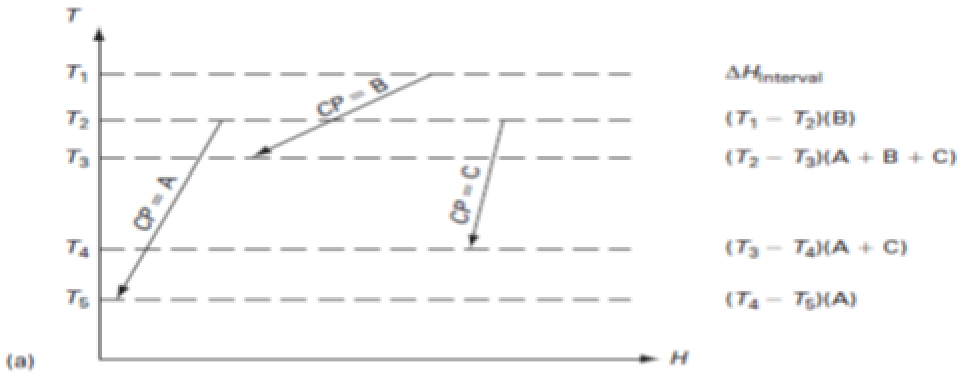


Figure (3-10.a) single composite of all hot streams

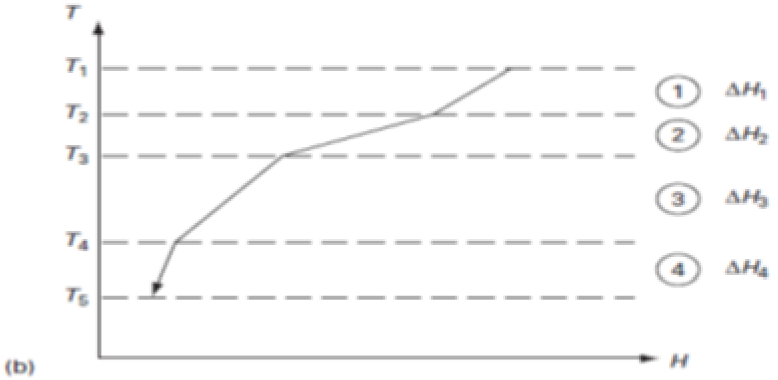


Figure (3-10.b) the result re-plotted against the interval temperatures

b. Grand Composite curve:

In selecting utilities to be used, determining utility temperatures, and deciding on utility requirements, the composite curves and PTA are not particularly useful. The introduction of a new tool, the Grand Composite Curve (GCC), was introduced in 1982 by Itoh, Shiroko and Umeda.

If the composite curves are re-plotted on axes of shifted temperature, we obtain the shifted composite curves. The shifted curves just touch at the pinch temperature, and show even more clearly than the composite curves that the pinch divides the process into two.

Now consider what happens at any shifted temperature S. The heat flow of all the hot streams QH, relative to that at the pinch QHP (fixed), is ΔQH. Likewise the heat flow of all cold streams relative to that at the pinch is ΔQC. There is an imbalance which must be supplied by utilities – external heating and cooling. Above the pinch, ΔQC > ΔQH and the difference must be supplied by hot utility. Likewise, below the pinch ΔQH >ΔQC and the excess heat is removed by cold utility.

Hence, knowing the shifted composite curves, we can find the minimum amount of heating or cooling that needs to be supplied at any given temperature. A graph of net heat flow (utility requirement) against shifted temperature can then easily be plotted.

This is known as the grand composite curve (hereafter abbreviated to GCC) figure (3-11) [8].

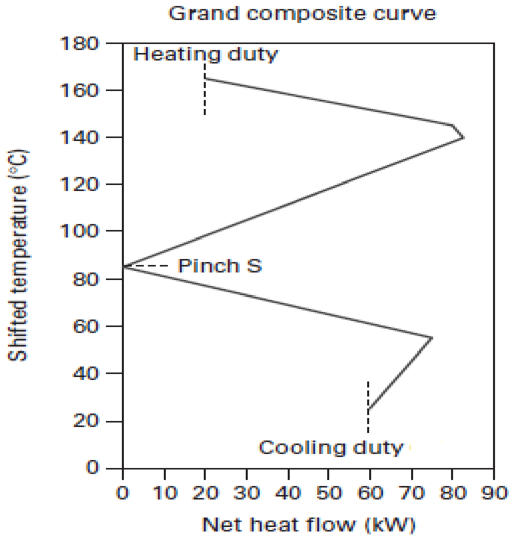


Figure (3-11) Grand Composite curve

3-4-4 Estimation of minimum energy cost target

The composite curves provide a counter-current picture of heat transfer and can be used to indicate the minimum energy target for the process. This is achieved by overlapping the hot and cold composite curves, as shown in Figure (3-7), separating them by the minimum Temperature difference DTmin. This overlap shows the maximum process heat recovery possible Figure (3-8). Indicating that the remaining heating and cooling needs are the minimum hot utility requirement (QHmin) and the minimum cold utility requirement (QCmin) of the process for the chosen DTmin.

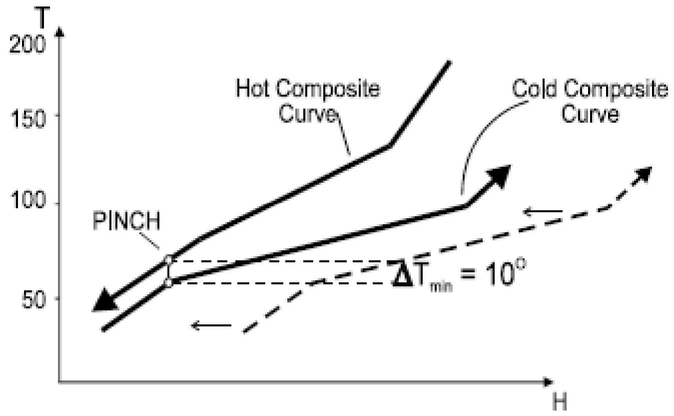


Figure (3-12) overlapping of the hot and cold composite curves

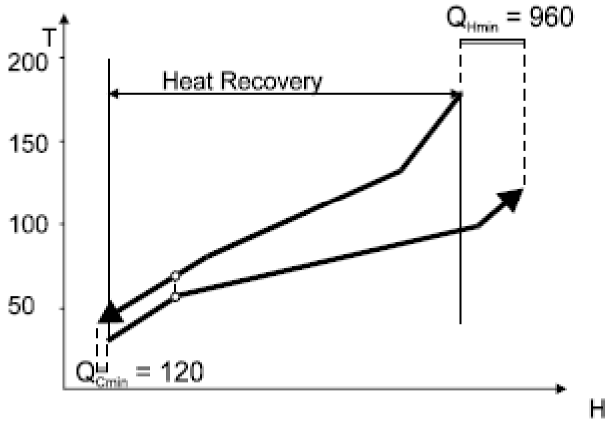


Figure (3-13) the maximum process heat recovery possible

The composite curves in Figures (3-7) & (3-8) have been constructed. Now the minimum hot utility (QHmin) can determined and comparing with the existing process energy consumption of units. The potential for energy saving is also can determined by using the same value of DTmin as the existing process. Using Pinch Analysis, targets for minimum energy consumption can be set purely on the basis of heat and material balance information, prior to heat exchanger network design.
This allows quick identification of the scope for energy saving at an early stage [9].

3-5 Design parameters of ktps (tables)

The Steam Generating Unit and its Auxiliaries are designed for the following parameters:-

Table (3-1) steam & feed water specification

Items	Unit	amount
Main steam		
Steam flow at SH outlet	t/h.	415
Steam pressure at SH outlet	Kg/cm2(g)	131
Steam temperature at SH outlet	°C	540
Reheat steam		
Reheat steam flow	t/h.	328.9
Steam pressure at RH inlet	t/h.	33.2
Steam temperature at RH inlet	°C	346.5
Steam pressure at RH outlet	Kg/cm2(g)	31.4
Steam temperature at RH outlet	°C	540
Feed water		
Feed water temperature at Inlet	°C	273.2

Table (3-2) fuel (Crude Oil) specification

Fuel composition (% wt.)	Unit	Crude Oil (guarantee fuel)
Carbon	%	85.32
Hydrogen	%	13.00
Sulphur	%	0.12
Moisture	%	1.00
Nitrogen	%	0.45
Ash	%	0.11
HHV	Kj/kg	44756.9

Table (3-3) Predicted performance of boiler (flow)

Description	Unit	amount
Steam		
Superheater outlet	t/h	378.3
Reheater outlet	t/h	309.1
Water		
Feed water	t/h	378.3
SH spray	t/h	4.8
Air		
Combustion Air	t/h	407.5
Flue Gas		
Flue gas at AH inlet	t/h	434.3
Flue gas at AH outlet	t/h	467.4

Table (3-4) Predicted performance of boiler (Pressures) for steam and water

Description	Unit	amount
Pressure		
Super heater outlet	kg/cm2 (g)	130.0
Hanger Platen SH outlet	kg/cm2 (g)	137.2
LTSH outlet	kg/cm2 (g)	139.3
Drum	kg/cm2 (g)	142.5
Economizer inlet header	kg/cm2 (g)	144.8
Reheater inlet	kg/cm2 (g)	31.21
Reheater outlet	kg/cm2 (g)	29.57
Pressure Drop		
Superheater system	kg/cm2	12.49
Reheater system	kg/cm2	1.64
Economizer (friction only)	kg/cm2	0.65

Table (3-5) Predicted performance of boiler (temperature)

Description	Unit	amount
steam		
Sat. temp. in Drum °	°C	337
LTSH terminal outlet	°C	424
SH hanger inlet	°C	415
SH hanger outlet	°C	428
SH hanger Platen outlet	°C	450
SH Finish outlet	°C	540
RH outlet	°C	336
RH outlet	°C	540
Water		
Economizer inlet	°C	235
Economizer outlet	°C	259
Air		
Ambient	°C	35
AH inlet	°C	48
AH outlet	°C	289
Gas		
SH hanger Platen inlet	°C	1177
SH Finish inlet	°C	1150
SH hanger 1 inlet	°C	995
RH inlet	°C	987
SH hanger 2 inlet	°C	746
SH hanger 2 outlet	°C	727
LTSH inlet	°C	694
Economizer inlet	°C	427
Air heater inlet	°C	353
Air heater outlet	°C	147

Table (3-6) Crude oil characteristics

Description	**Unit of Measurement**	**Whole Crude**
Density @ 15°C	Kg/ltr	0.8955
Specific gravity @ 60°F		0.896
Sulphur	% wt	0.116
Mercatan Sulphur	mg/ kg	1
Hydrogen Sulphide	mg/ kg	<1
Total Nitrogen	%wt	0.449
Kinematic Viscosity @ 55 °C	cst	108.7
Kinematic Viscosity @ 100 °C	cst	22.61
Total Chloride	mg/kg	11
Total Acid number	mgKOH/g	2.8
Wax Content	% wt	19.8
Nickel	ppm Wt	57.80
Iron	ppm Wt	7
Ash Content	% wt	0.036
Water Content	% vol	1.7
Pour Point	°C	+42

[11]

3.6 Applying the pinch technology to thermal power plant:

the steam is generated in Boiler which is the steam directly sent to the high pressure turbine (HP), at the exhaust of the high pressure turbine the steam is sent back to the steam generator for the reheating purpose. This reheated steam is sent to the intermediate pressure turbine (IP). At the exhaust of the intermediate pressure turbine (IP), the steam is sent to the low pressure turbine.

At the exhaust from the low pressure turbine (LP) the steam is sent to the condenser for condensation purpose. Here the cooling water is used as the cooling duty for the condensation of steam. From the outlet of the condenser the condensate is sent from the pump to the feed heater as shown in the below diagram figure (3.14). Here the heat exchange will take place between the condensate and the extracted steam from the turbines extraction. This will cause the rise in the temperature of the condensate. Similarly the condensate will be sent to further phases of heating from the different extraction of the intermediate and the high pressure turbine.

Finally the condensate at the exit of the feed heater will be sent to the steam generator for generation of steam. Crude oil as fuel is being used as the heating utility inside the steam generator. Thus the input energy of the cycle will be the fuel used in the steam generator and the output of the cycle will be the turbine work. Whereas, the cooling duty is the cooling water used for the steam condensation in the Condenser.

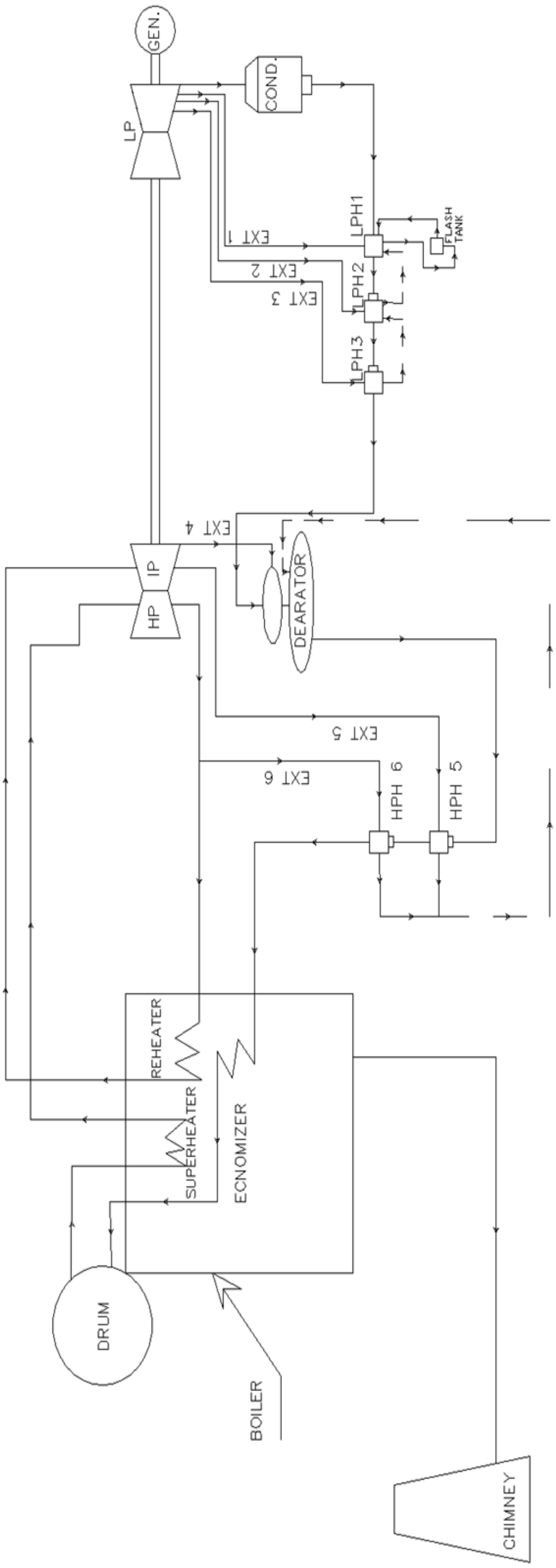


Figure (3-14) schematic diagram for the functioning of a steam cycle power plant

3.7 pinch calculation:

3.7.1 The present Utility consumption of the plant

The present utility consumption of the plant, can be found out from the below data. The plant is a crude oil fired plant and the crude used is of the heating value of42000 kJ/kg. The consumption of the crude is found to be 7.8 kg/sec. Thus from this data the hot utility consumption of the plant can be given as:

Hot Utility = Mass of crude oil x Heating value of crude oil (3.8)

= 7.8 Kg/s x 42000 kJ/kg

= 326666 KJ/s = 326.666 MW.

The mass flow rate of cooling water is 4555.5 Kg/s. The temperature difference between the inlet and outlet of cooling water for the condenser is 12°C. (40-28) considering the specific heat of the cooling water to be 4.187 KJ/Kg K. the cooling duty is:

Cooling Duty = Mass flow rate of water x specific Heat x temperature difference (3.9)

= 4555.5 x 4.187 x 12

= 228886.5 KJ/s

= 228.8865 MW.

η = Turbine Output power / Hot utility consumption (3.10)

= 125 / 326.666

= 0.38

= 38%

Thus the plant efficiency is 38%.

. [11]

Table (3-7) specification of hot and cold streams in the plant:

No.	Stream Name	Stream Type	Supply temp (Ts) °C	Target temp (Tt) °C	Heat Capacity flow rate (Kw/K) CP= m*cp	Enthalpy Change (KW)
1	HPT	HOT	530	302	192	43776
2	IPT	HOT	528	289	192	45888
3	LPT	HOT	287	56	177.3	40956.3
4	EXTRACTION1	HOT	97	68	8.44	245
5	EXTRACTION2	HOT	115	73	9	378
6	EXTRACTION3	HOT	204	96	10.2	1102
7	EXTRACTION4	HOT	288	148	11.2	1568
8	EXTRACTION5	HOT	414	152	17	4454
9	EXTRACTION6	HOT	330	229	31.4	3171.4
10	LPH1	COLD	47	66	415	7885
11	LPH2	COLD	64	91	415	11205
12	LPH3	COLD	87	117	415	12450
13	DEARATOR	COLD	116	148	415	13280
14	HPH5	COLD	147	191	434	19096
15	HPH6	COLD	189	235	434	19964
16	ECNOMIZER	COLD	233	257	434	10416
17	SUPER HEATER	COLD	332	535	215	43775
18	RE HEATER	COLD	300	530	215	49450

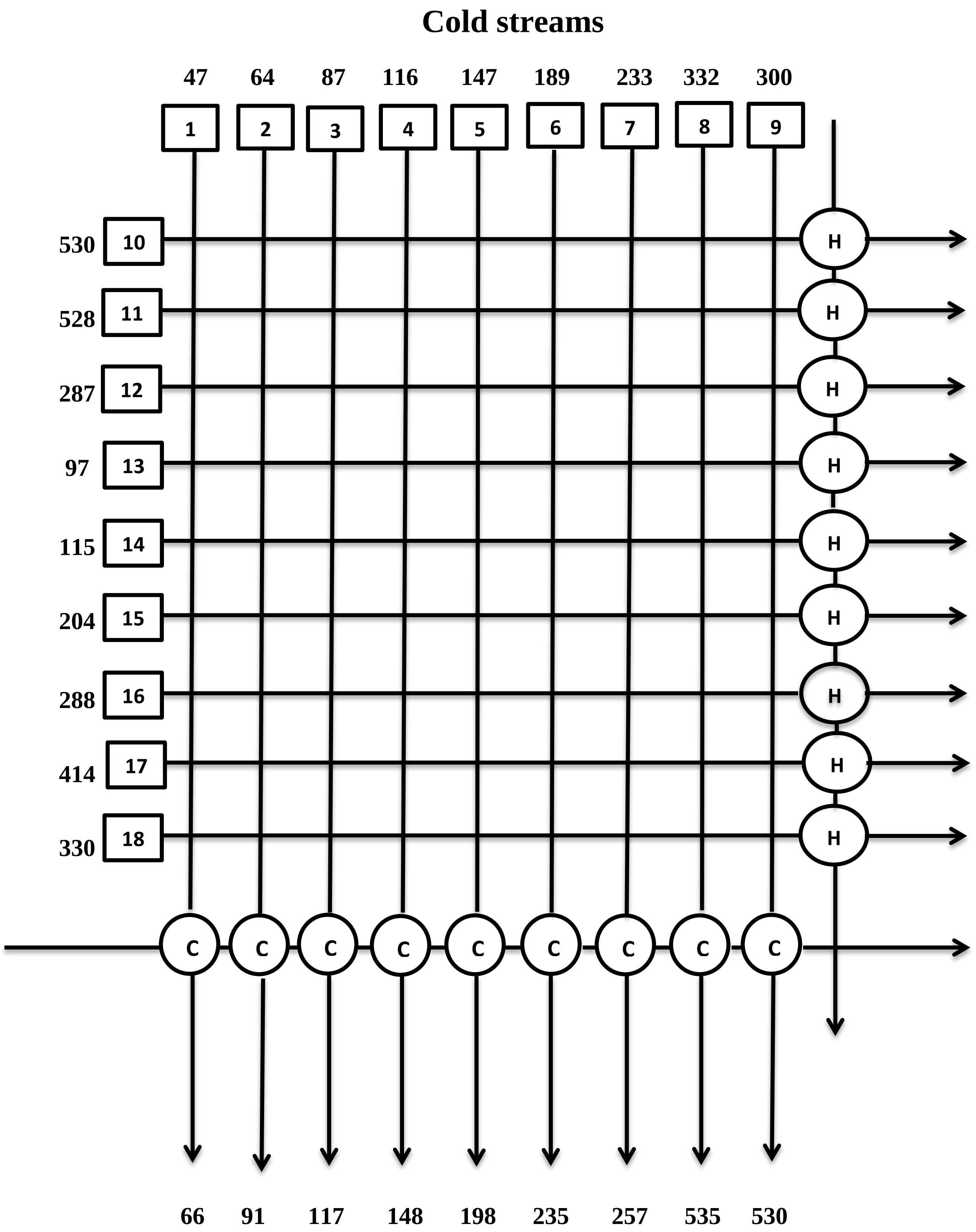


Figure (3.15) direct heat transfer between the fluid streams and the hot and cold utilities

Table (3.8) ordering of hot and cold streams

No.	Stream Name	Stream Type	Supply temp (Ts) °C	Target temp (Tt) °C	Adjusting temperature		Ordering	
1	HPT	HOT	530	302	520	292	T3	T9
2	IPT	HOT	528	289	518	279	T4	T10
3	LPT	HOT	287	56	277	46	T12	T35
4	EXTRACTION1	HOT	97	68	87	58	DUBLE	T33
5	EXTRACTION2	HOT	115	73	105	63	T26	T32
6	EXTRACTION3	HOT	204	96	194	86	T17	T29
7	EXTRACTION4	HOT	288	148	278	138	T11	T23
8	EXTRACTION5	HOT	414	152	404	142	T5	T22
9	EXTRACTION6	HOT	330	229	320	219	T7	T16
10	LPH1	COLD	47	66	47	66	T34	T30
11	LPH2	COLD	64	91	64	91	T31	T27
12	LPH3	COLD	87	117	87	117	T28	T24
13	DEARATOR	COLD	116	148	116	148	T25	T20
14	HPH5	COLD	147	191	147	191	T21	T18
15	HPH6	COLD	189	235	189	235	T19	T14
16	ECNOMIZER	COLD	233	257	233	257	T15	T13
17	SUPER HEATER	COLD	332	535	332	535	T6	T1
18	RE HEATER	COLD	300	530	300	530	T8	T2

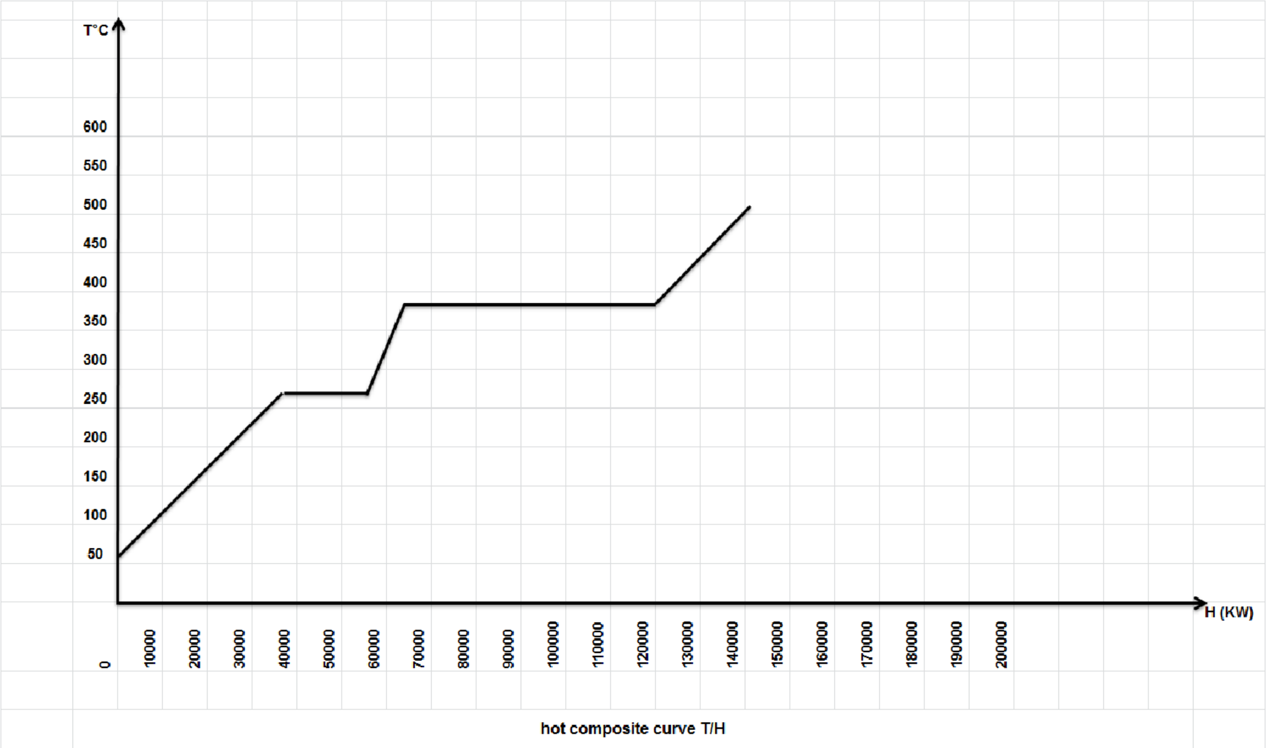


Figure (3.16) hot composite curve

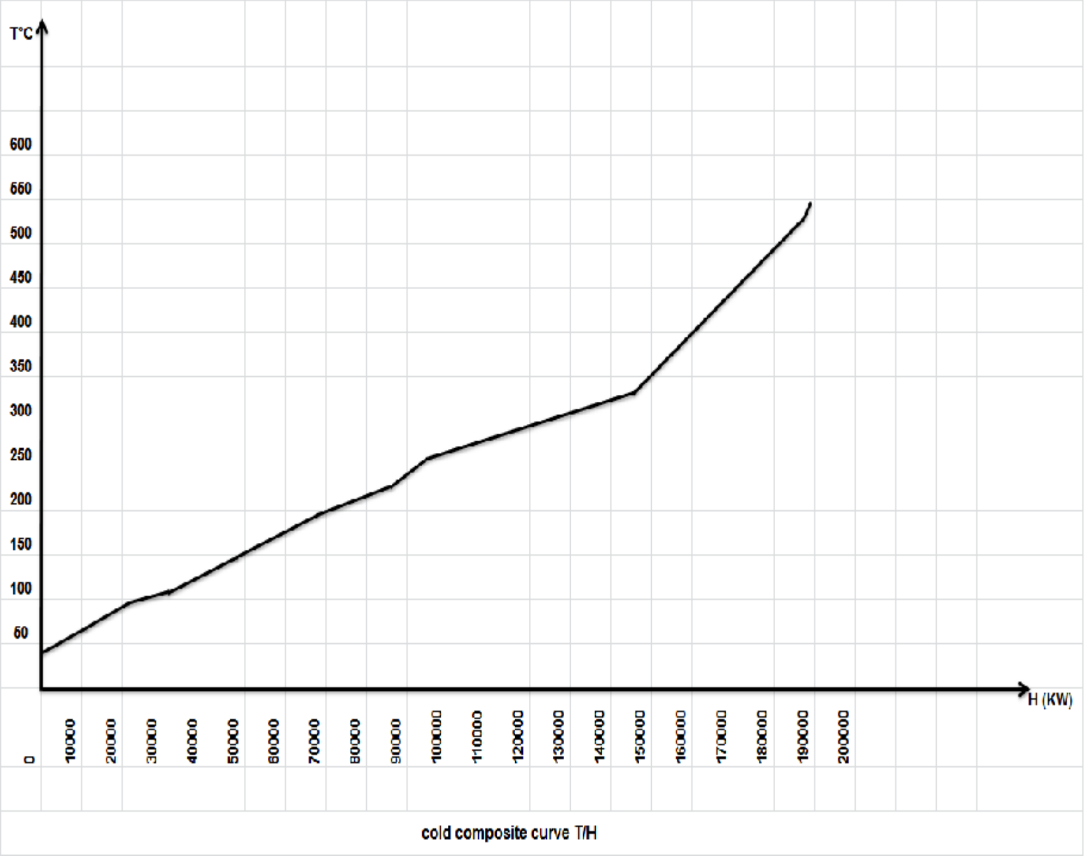


Figure (3.17) cold composite curve

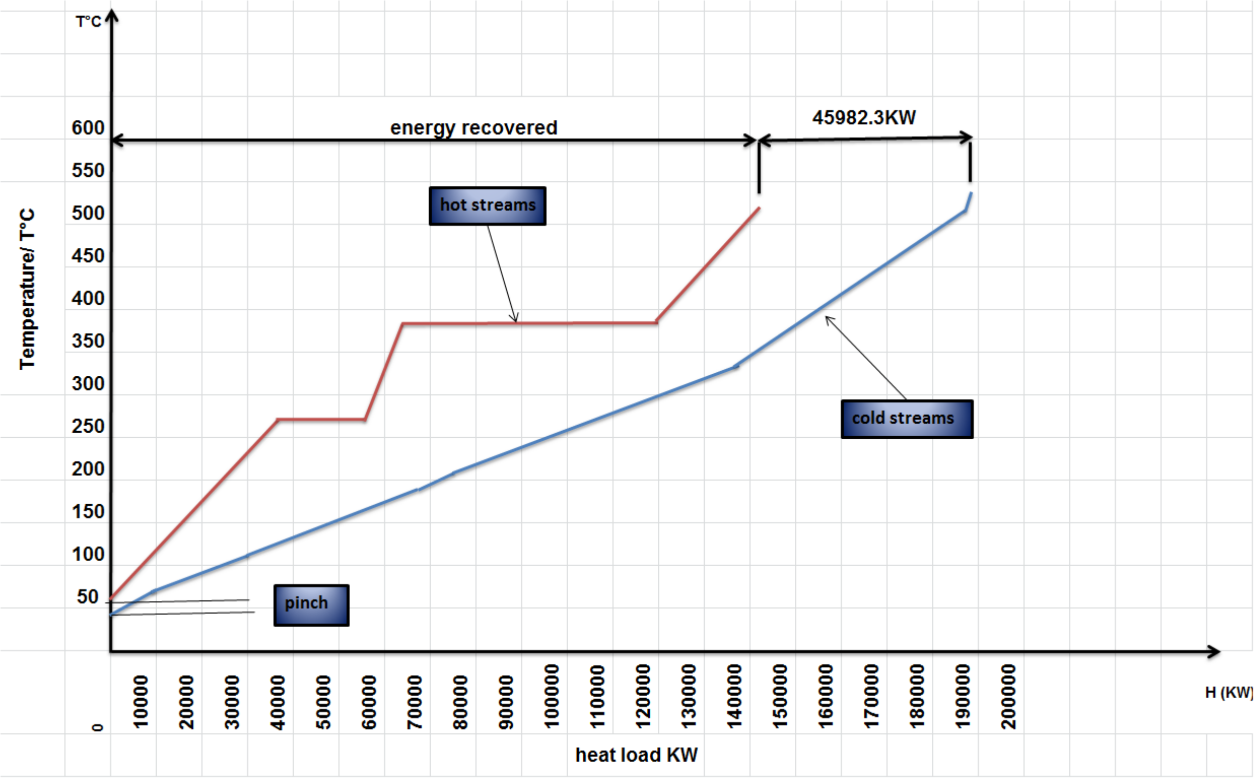


Figure (3.18) hot & cold composite curve

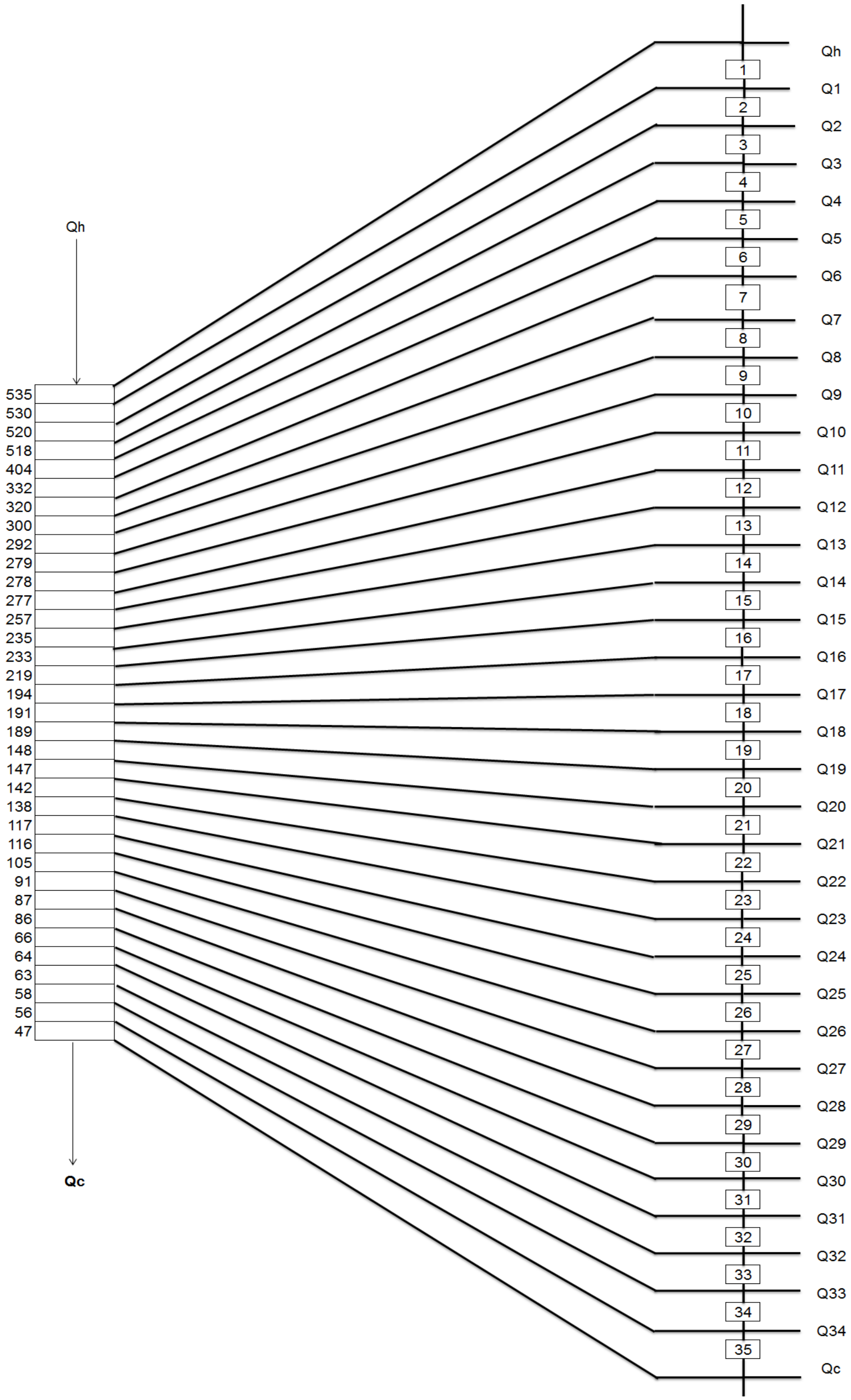
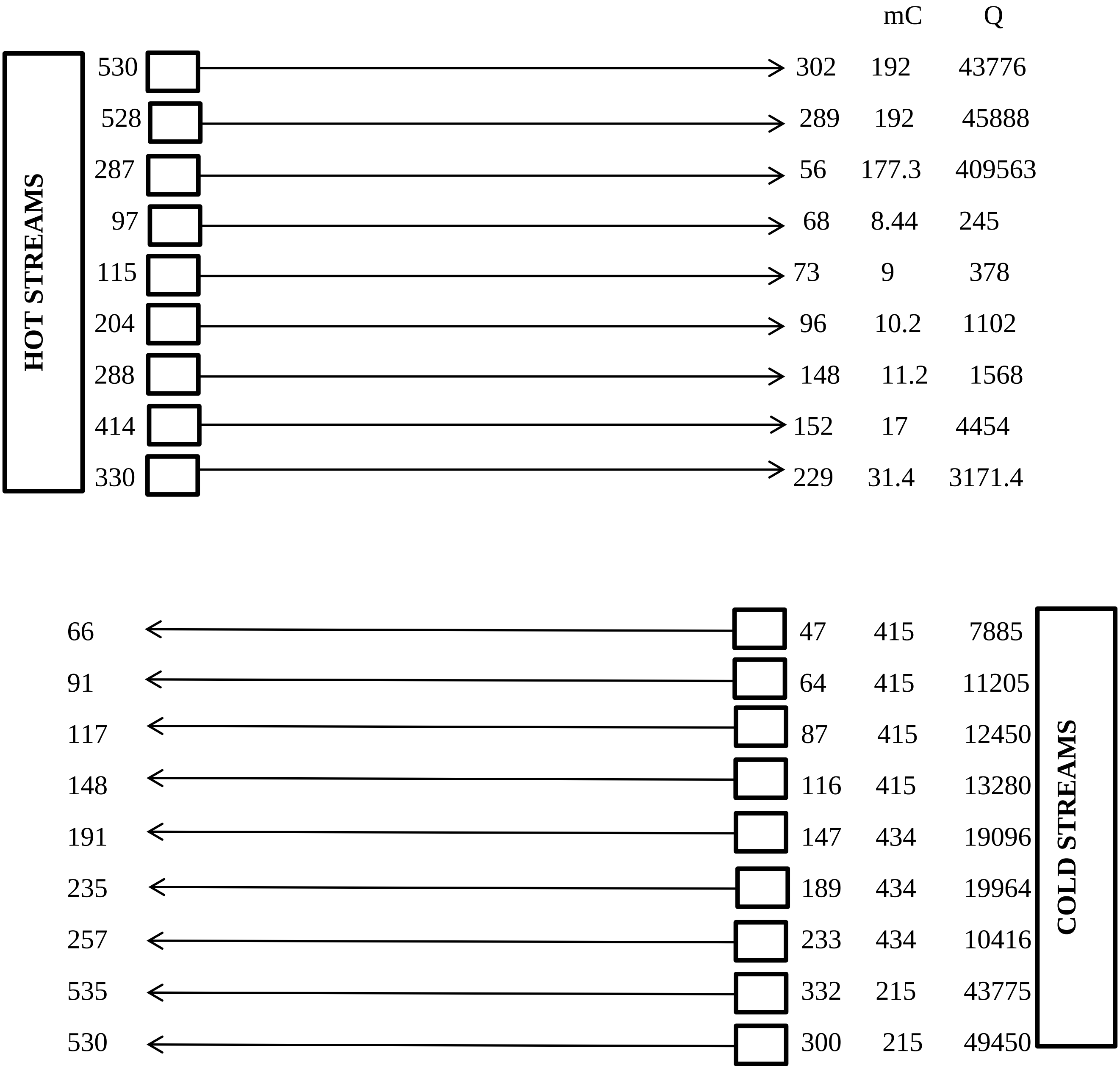


Figure (3.19) temperature interval for heat transfer

Table (3.9) overall energy for heat transfer net work

	streams	mC$^{\delta}$ t	ΣmC$^{\delta}$ t	(+)53050.3
535				
	17	-1075		
530			-1075	51975.3
	17,18	-4300		
520			-5375	47675.3
	17,18,1	-476		
518			-5851	47199.3
	17,18,1,2	-5244		
404			-11095	41955.3
	17,18,1,2,8	-2088		
332			-13183	39867.3
	18,1,2,8	-2232		
320			-15415	37635.3
	18,1,2,8,9	4348		
300			-11067	41983.3
	1,2,8,9	3459.2		
292			-7607.8	45442.5
	2,8,9	721.2		
279			-6886.6	46163.7
	8,9	48.4		
278			-6838.2	46212.1
	8,9,7	59.6		
277			-6778.6	46271.7
	8,9,7,3	4738		
257			-2040.6	51009.7
	8,9,7,3,16	-4336.2		
235			-6376.8	46673.5
	8,9,7,3,16,15	-1262.2		
233			-7639	45411.3
	8,9,7,3,15	-2759.4		
219			-10398.4	42652
	8,7,3,15	-5712.5		
194			-16110.5	36939.8
	8,7,3,15,6	-655		
191			-16766	36284.3
	8,7,3,15,6,14	-1304.6		
189			-18070.5	34979.8
	8,7,3,6,14	-8950.3		
148			-27020.8	26029.5
	8,7,3,6,14,13	-633.3		
147			-27654.1	25396.2
	8,7,3,6,13	-996.5		
142			-28650.6	24399.7
	7,3,6,13	-865.2		
138			-29515.8	23534.5
	3,6,13	-4777.5		
117			-34293.3	18757
	3,6,13,12	-642.5		
116			-34935.8	18114.5
	3,6,12	-2502.5		
105			-37438.3	15612
	3,6,12,5	-3059		
91			-40497.3	12553
	3,6,12,5,11	-2534		
87			-43031.3	10019
86	3,6,5,11	-218.5		
66			-43249.8	9750.5
	3,5,11	-4574		
64			-47823.8	5226.5
	3,5,11,10	-1287.4		
63			-49111.2	3939.1
	3,5,10	-228.7		
58			-49339.9	3710.4
	3,10	-1188.5		
47			-50528.4	2522
	3,10,4	-2521.9		
46			-53050.3	0 ← PINCH POINT
	3,4	185.7		
			-25864.6	185.7



		mC	Q
530	302	192	43776
528	289	192	45888
287	56	177.3	409563
97	68	8.44	245
115	73	9	378
204	96	10.2	1102
288	148	11.2	1568
414	152	17	4454
330	229	31.4	3171.4

66	47	415	7885
91	64	415	11205
117	87	415	12450
148	116	415	13280
191	147	434	19096
235	189	434	19964
257	233	434	10416
535	332	215	43775
530	300	215	49450

Figure (3.20) initial heat transfer

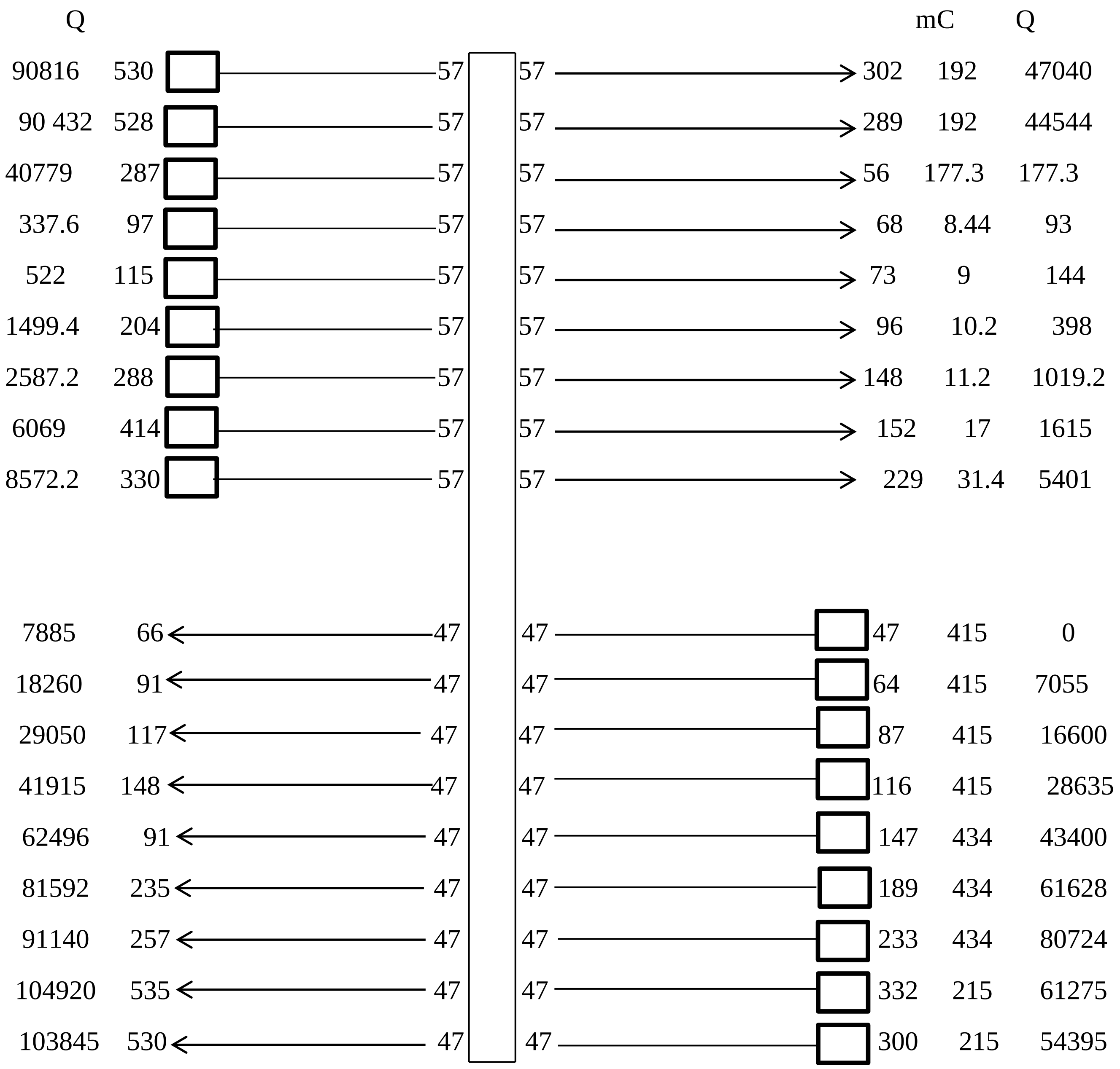


Figure (3.21) hot and cold streams with pinch

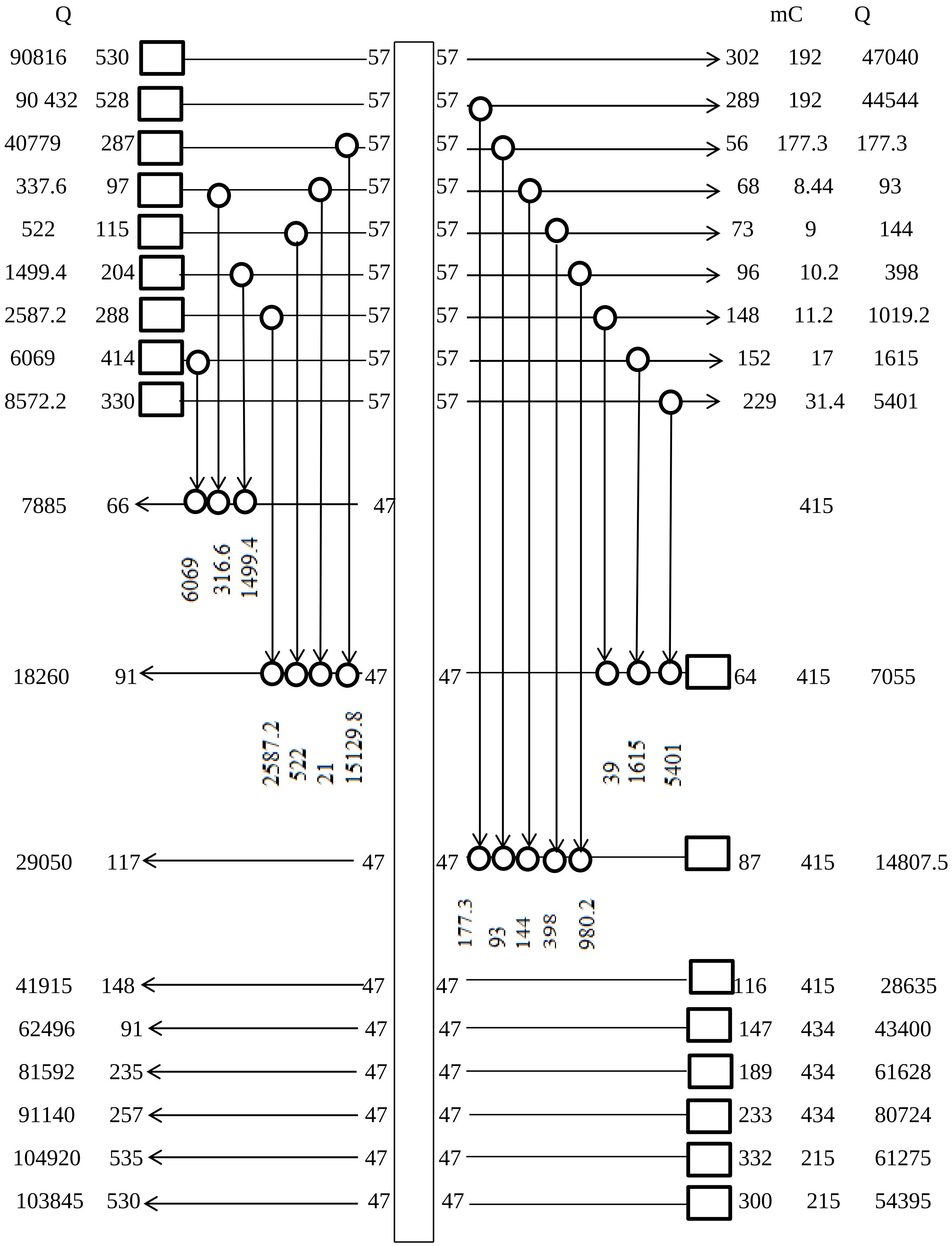


Figure (3.22.a) heat transfer from streams to other streams

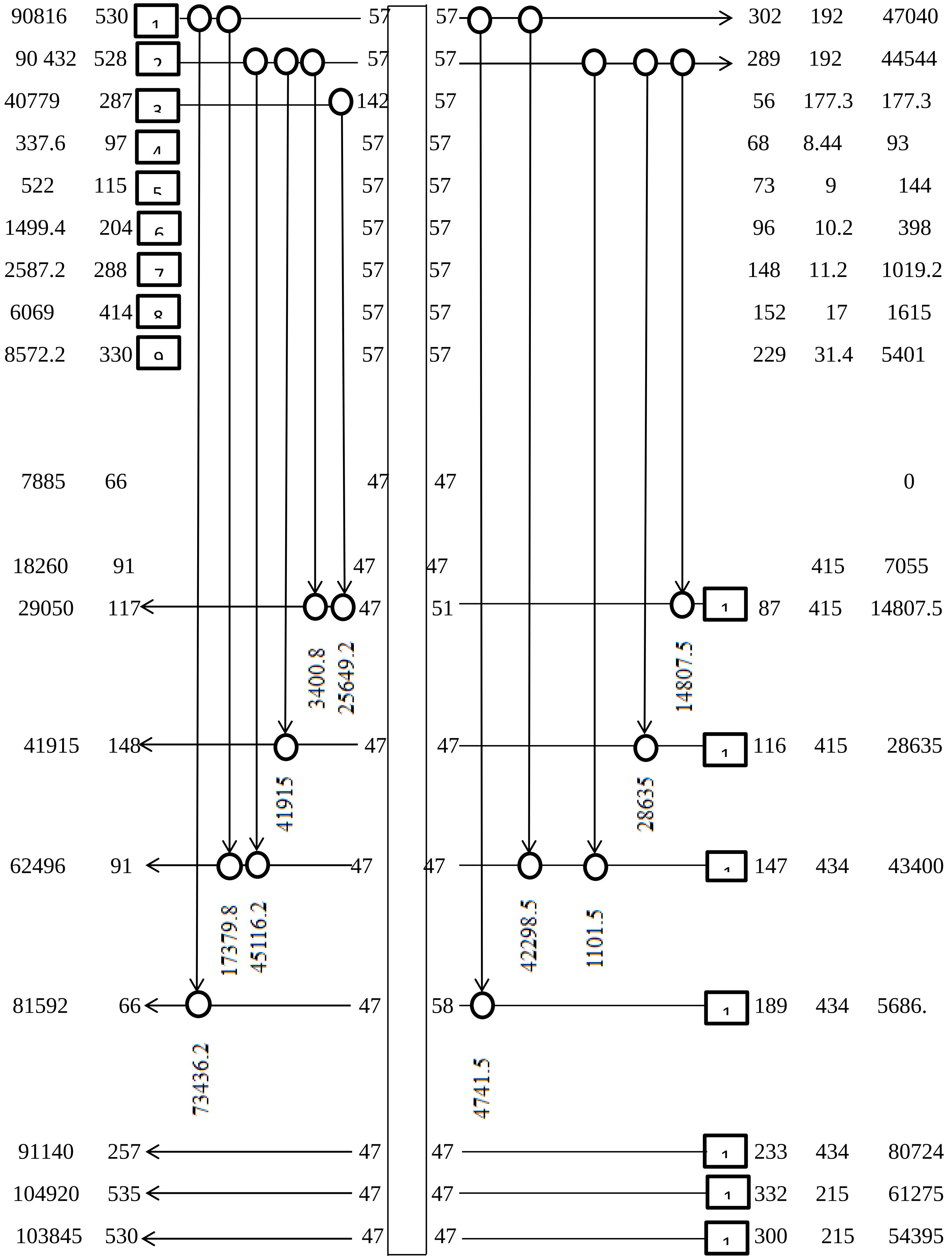


Figure (3.22.b) heat transfer from streams to other streams

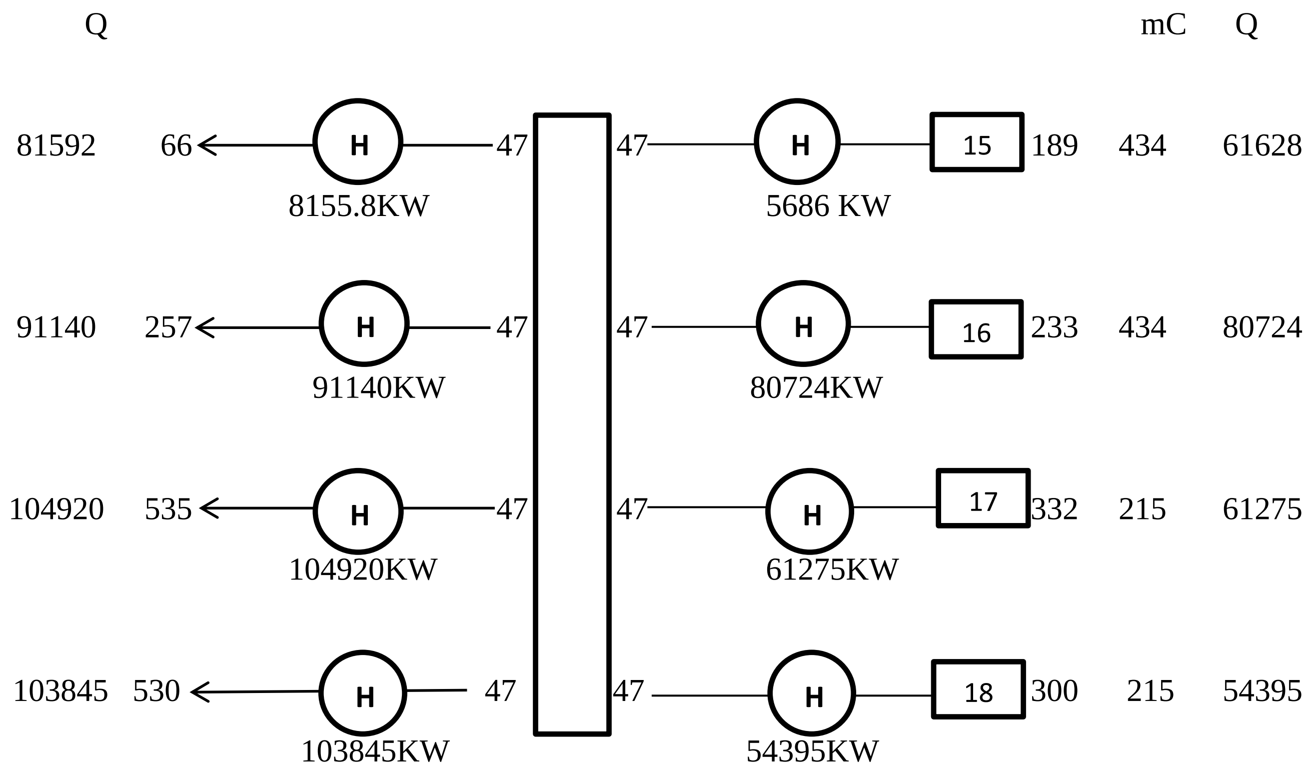


Figure (3.23) composite diagram for heat transfer net work

CHAPTER IV

Results and discussion

CHAPTER IV

Results and discussion

4-1 Results and Discussion:

This data has been taken from pinch parameter calculated in chapter V.

4-2 specification of hot and cold streams:

From specification of hot and cold streams in the plant in table (3.7) we found that:

Minimum hot utility requirement =**141538.7KW**
Minimum cold utility requirement = **187521KW**

In this case there are nine streams of fluid which require cooling (the hot streams) and nine streams of fluid which require heating (the cold streams).The simplest way of achieving this is to cool the hot streams by transferring heat directly to a cold water supply, and to heat the cold streams by means of a steam supply; this approach is shown in Figure (3.15) This means that the hot utility (the steam supply) has to supply **187521KW** of energy, while the cold utility (a cold water supply) has to remove **141538.7KW** of energy.

Both of these utilities are a cost on the process plant. The steam has to be produced by burning a fuel, and use of the cold water will be charged by the water authority.

In reality minimum net heat supply = 18752 - 141538.7 = 45982.3 KW could achieve the same result, if it were possible to transfer all the energy available in the hot streams to the cold streams.

If heat is going to be transferred between the hot and cold streams there must be a temperature difference between the streams:

*Assume in this case that the minimum temperature difference (ΔTmin) is 10°C.

4-3 the unadjusted temperatures of hot and cold streams:

From table (3.8). The unadjusted temperatures of the cold streams can be used, and the hot stream temperatures can be adjusted by subtracting (ΔTmin) is 10°C, from the actual values. In this way the effect of the minimum temperature difference has been included in the calculation.

The parameters defining the streams can also be shown on a diagram of temperature against heat load (enthalpy transfer; see Fig (3.18). This diagram has been evaluated using the data in Table (3.8) and is based on the unadjusted temperatures. The hot stream line is based on the composite temperature-heat load data for the hot streams figure (3.16). The cold stream also is based on the composite temperature-heat load data for the cold streams figure (3.17). It can readily be seen that the two lines are closest at the temperature axis, when they are **9°C**: this means that there is **'pinch'** in this study because the temperature difference at the pinch point is less than the minimum value allowable.

4-4 allocating of energy transfers:

From figure (3.18).Hence, the problem reduces to transferring energy from the hot streams to the cold streams, and finally adding **45982.3 KW** from a hot utility.

The mechanism for allocating the energy transfers will now be introduced.

Having defined the temperature intervals it is possible to consider the problem as shown in Figure (3.19). The energies flowing into and out of the combined systems, Qh and Qc, are those which have to be supplied by and lost to the external reservoir respectively. It is also apparent that the difference between these values is the difference between the enthalpies of the hot and cold streams, i.e.

$$\mathbf{Qc - Qh = \delta H} \qquad \mathbf{(4.1)}$$

Consideration will show that δH is constant, because the difference between the enthalpies of the hot and cold streams is constant, and this means that any additional energy added from the high temperature supplies must be compensated by an equal amount of energy being rejected to the low temperature sinks: hence energy will have just flowed wastefully through the overall system.

4-5 effect of minimum temperature difference:

From table (3.8). Now we can see the effect of minimum temperature difference between streams, and hence the interval has been established so that full heat transfer is passible between the hot and cold streams.

It is now necessary to apply the first law to examine the enthalpy balance between the streams, when:

$$\boldsymbol{\delta}\mathbf{Hi} = \left(\sum\nolimits_{i,i-1}^{hot} (mC)_h - \sum\nolimits_{i,i+1}^{cold} (mC)_h \right)(T_i - T_{i+1}) \qquad \mathbf{(4.2)}$$

Where:

i = initial temperature of the interval

i+1 = final temperature of the interval **(4.3)**

Applying this equation to this study, the results in the heat flows shown by:

δH = mCδT values in table **(4-4)**

4-6 the pinch result:

From the problem table cascade shown in Table (3.9) following information is extracted:

Amount of minimum hot utility required: 53050.3 kW

Amount of minimum cold utility required: 185.7 kW

Pinch point: 47°C

Hot pinch: 57°C

Cold pinch: 47°C

The demand of the cold streams exceeds the total energy available from the hot streams, and it is at point that the energy should be added from the hot utilities. Because this will limit the temperature required in the hot utility. In reality, the 53050.3 KW could be provided from the hot utility at any temperature above 47°C.

It is now useful to look at the way in which the heat can be transferred between the hot and cold streams.

Also from figure (3.23).We can seeing clear that all being stream need for heating, this mean that we have more amount of cold water as loses in the plant and this well reduced the efficiency of the plant.

Chapter V

Conclusion & Recommendation

ChapterV
Conclusion & Recommendation

5-1 Conclusions

From this work, it can be concluded that the existing energy intake from utilities is 510140.8 KW with 0 kW needed for cooling and 510140.8 kW needed for heating.

However using pinch analysis with ΔTmin = 10˚C, it is found that the minimum energy requirements are **53050.3 KW** for the heating, the minimum energy requirements are **185.7 KW** for the cooling, the maximum energy recovered during process exchange being **141538.7KW**, The Pinch point at 47°C, The Hot pinch at 57°C and The cold pinch at 47°C.

A method has been introduced for improving the efficiency of energy transfers in complex Plant. It has been shown that in some plants there is a pinch point which restricts the freedom to transfer energy between process streams. To ensure that the plant attains its maximum efficiency of energy utilization, energy should be added to the system only above the pinch, and extracted from it only below the pinch.

5-2 Recommendations

It is recommended that:

- A heat exchange network (HEN) can be designed for the brewery process based on the targets obtained in this study for efficient energy implementation.
- Pinch analysis be applied using various temperatures in the range obtained from the energy targets vs. Δ Tmin since reduction would increase the heat recovery.
- also we can use The technique of time average model (TAM) in this work, it well give similar results to an assumed continuous process however most brewery configurations are effected as batch processes this may be considered to give more realistic energy targets.
- there is much amount of cold water un used as we seeing in the pinch analysis, this should use in heat exchanger or should reduce because already it considered loses, that well reduce the total plant efficiency (chemical process very cost).

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