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Master Program of Renewable Energy and Sustainability

Thermal Energy Integration of Milk Pasteurization Process Using Pinch Analysis: A Case Study of Al-Junaidi Company for Food and Dairy Products

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Thesis submitted in partial fulfillment of requirements of the degree

Master of Science in Renewable Energy & Sustainability

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Thermal Energy Integration of Milk Pasteurization Process Using Pinch Analysis: A Case Study of Al-Junaidi Company for Food and Dairy Products

BY: Zidan Mahmoud Taha

ABSTRACT

The increasing cost of fossil fuels and their harmful effects to the environment shed the light on the necessity of efficient industrial processes in order to reduce energy consumption and CO_2 emissions. Fossil fuels remain the most widely used among the different energy sources. More than 80% of the total global consumed energy is produced by burning fossil fuels. This is due to their rate of commercialization and their extraction development in technology.

Industry sector is responsible for 30% of the global final energy consumption. Despite the rapid development of alternative energy sources, the effective use of the traditional sources can't be neglected. Energy integration techniques are commonly used to improve the efficiency of processes in industry. Pinch technology is widely used to utilize energy in dairy production processes. The application of pinch analysis on 3 milk pasteurizers in Al-Junaidi Company for Dairy and Food Products is presented in this study.The studied pasteurizers consisted of 3 hot streams and 3 cold streams. The total heating load required for the cold streams is 2032.5 kW, while the total cooling load required for the hot streams is 1802.4 kW.

The heat exchanger network design result into a retrofit of 6 heat exchangers. If the retrofit could be implemented, the required external heating load could be reduced to 275 kW and the external cooling load could be reduced to 45 kW. The CO_2 emissions could be reduced from 484 tons CO_2/year to 263 tons CO_2/year. Danfoss Hexact V5 selection tool is used in order to select the required heat exchangers. The selected heat exchangers indicates 65% saving of the heating load, and 8% of the cooling load. The capital cost of the design is 60400 NIS and the annual savings for this design are 374195 NIS with a simple payback period of 2 months.

تكامل الطاقة الحرارية لعملية بسترة الحليب باستخدام (Pincch Technology) : دراسة حالة لشركة الجنيدي للأغذية ومنتجات الألبان

اعداد: زيدان محمود طه

الملخص:

لقد سلط الازدياد المستمر في أسعار الوقود الاحفوري و أثره المدمر على البيئة الضوء على اهمية استخدام اساليب صناعية عالية الكفاءة من اجل تقليل استهلاك الطاقة و انبعاثات غاز ثاني اكسيد الكربون. لا يزال الوقود الأحفوري هو المصدر الأكثر استخداماً من بين المصادر المختلفة للطاقة. حيث أن أكثر من 80% من المجموع العالمي لاستهلاك الطاقة ناتج عن حرق الوقود الأحفوري، وهذا يعود للتطور الكبير في عمليات استخراجه.

يستهلك قطاع الصناعة حوالي 30% من مجموع استهلاك الطاقة العالمي. على الرغم من التقدم المتسارع لانتشار مصادر الطاقة البديلة، الا أنه لا يمكن غض النظر عن الاستعمال الفعال للمصادر التقليدية. يتم استخدام تقنية Pinch Technology بشكل واسع بهدف استغلال كفاءة الطاقة في العمليات الصناعية. من خلال هذه الدراسة تم تطبيق هذه التقنية على ثلاثة مبسترات للحليب في شركة الجنيدي لصناعة الألبان والمواد الغذائية. تتكون المبسترات التي تم تحليلها من 3 تيارات ساخنة و3 تيارات باردة. ومن الجدير بالذكر أن مجموع حمل التخسين المطلوب 2032.5 كيلو واط، بينما بلغ مجموع الحمل النهائي للتبريد 1802.5 كليو واط.

سيضيف تصميم شبكة المبادلات الحرارية تعديل على القسم من خلال استخدام 7 مبادلات حرارية. في حال تطبيق التعديل سينخفض حمل التسخين الخارجي المطلوب الى 275 كيلو واط، فيما سينخفض –حمل التبريد الخارجي الى 45 كيلو واط. كما أن انبعاثات ثاني أكسيد الكربون ستنخفض من 484 طن في السنة الى 263 طن في السنة. استخدمت أداة Danfoss Hexact V5 لاختيار المبادلات الحرارية المطلوبة. المبادلات الحرارية التي تم اختيارها من خلال هذه الأداة تشير الى توفير 65% من حمل التسخين المطلوب و 8% من حمل التبريد المطلوب. تبلغ التكلفة الرأسمالية المطلوبة لتنفيذ التصميم 60400 شيكل بينما يبلغ التوفير السنوي حوالي 374195 شيكل مع فترة استرداد حوالي شهرين.

DECLARATION

I declare that the Master Thesis entitled" **Thermal Energy Integration of Milk Pasteurization Process Using Pinch Analysis: A Case Study of Al-Junaidi Company for Food and Dairy Products**" is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

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Student Name: **Zidan Mahmoud Taha**

Signature: ______________________________ Date:____________________

DEDICATION

To my family ………………. For their support

To my teachers …….......... For help me until the end

To my friends ………………. Who give me positive sentiment

To oppressed people throughout the world and their struggle for social justice and egalitarianism

To our great Palestine

To my supervisor Dr Zudi Salhab

To all who made this work possible

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Finally, my ultimate thanks go to the great edifice of science **(Palestine Polytechnic University)**.

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LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
COPT	Crude Oil Preheat Train
FCs	Heat Capacity Flowrates
GCC	Grand Composite Curve
HEN	Heat Exchangers Network
HEX	Heat Exchanger
IEA	International Energy Agency
KTOE	Kilo Tons of Oil Equivalent
NPA	Network Pinch Approach
PA	Pinch Analysis
PM	Pinch Methodology

LIST OF SYMBOLS

Variables	Units	Description
C_e	Unit cost	Cost of electricity
cp	kJ/kg.K	Specific heat
F_{cp}	kW/ °K	Heat Capacity Flowrates
ΔH	kW	Enthalpy Rate
$\dot{M}$	kg/sec	Mass flow rate
P_r	W	Required Power
ΔP	Unit Cost	Capital Cost
P	W	Electrical Power
p_e	NIS/kWh	Price of electrical energy
Q	W	Heat Duty
ρ	kg/m3	Density
S	Unit Cost/year	Annual Savings
t	Hours	Time
ΔTmin	°C or °K	Minimum Temperature Difference
ΔT	°C or °K	Temperature Difference
$\dot{V}$	m^3/s	Volume Flow Rate

Chapter 1: Introduction

1.1 Introduction:

Industry development and the increasing world population are considered the main contributors that affect global energy demand. As these two factors are continuously on the rise, this leads the world demand for energy to be continuously on the rise. Fossil fuels remain the most widely used among the different energy sources (fossil fuels, wind, solar, hydro, geothermal, and so on). This is due to their rate of commercialization and their extraction development in technology. Total global energy consumption by industry increased from 1803743 KTOE (Kilo Tonnes of oil equivalent) in 1990 to 2820887 KTOE in 2017 according to the International Energy Agency (IEA) [1]. Approximately, 80% of this quantity was produced by burning fossil fuels [1]. Although there is likely to be a remarkable improvement in the use of renewable energy, fossil fuels still playing a dominant role in world energy sources, see Figure 1.1. This indicates that fossil fuels will still have a major role to play in the production of energy and will undoubtedly continue to dominate for the coming years.

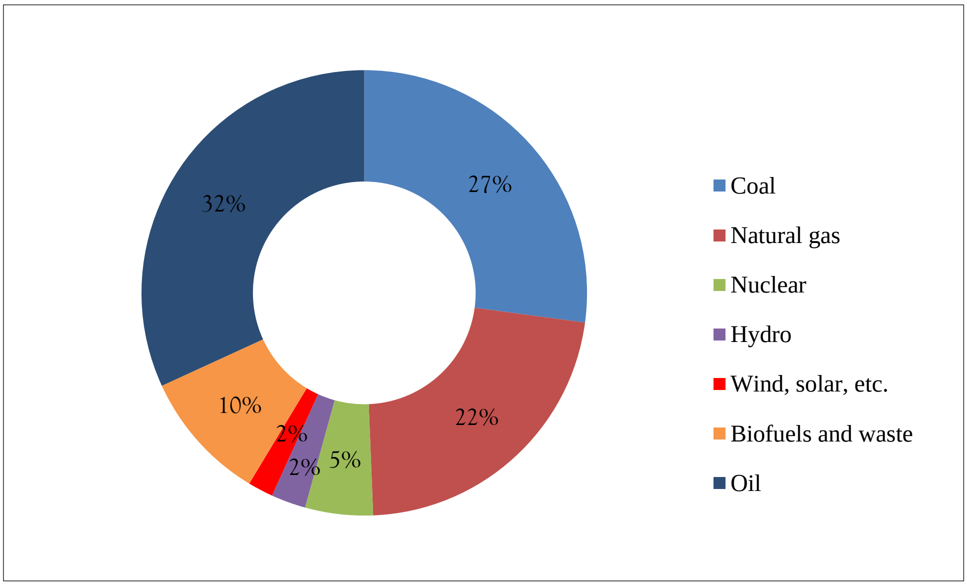


Figure 1.1: Total primary global energy supply by source (IEA 2017)

Industry uses a significant quantity of total energy consumption in developed countries. The percentage of energy consumption by industry though, is different from country to country. As can be estimated from Figure 1.2, industry accounted for 30% of the global final energy consumption in 2017 [1].

Fossil fuel has been confirmed as the major single source of anthropogenic CO_2, in addition to the fact that it is an exhaustible energy source, CO_2 emissions by fossil fuel usage believed to be responsible for causing global warming and ultimately climate change.

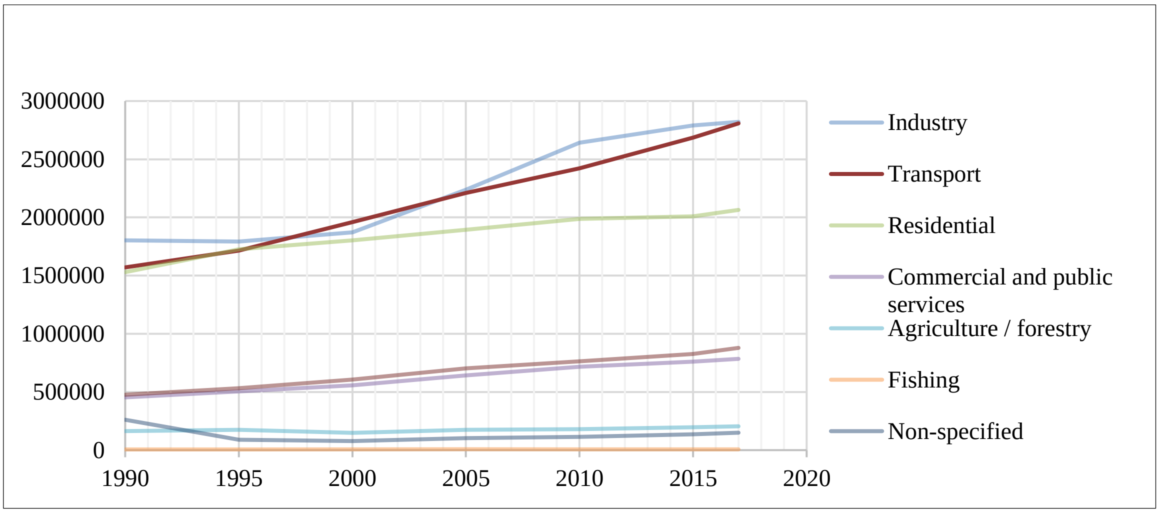


Figure 1.2: Total global energy consumption by sector (IEA 2017)

Lately, the over-dependence on fossil fuels for energy generation has been a global issue. It is not only because of their exhaustible nature, but also because of their negative environmental impact. These global concerns have led world leaders to beat the drum for the development of alternative cleaner sources of energy to reduce the domineering and negative effect of using fossil fuels as an energy source.

Therefore, while we seek to develop alternative energy sources to produce cleaner energy, it is necessary to use resources effectively in the meantime in order to reduce the amount of fossil fuels used. This can be achieved by reducing waste of energy as well as efficient recovery of waste energy.

1.2 Motivations:

Waste heat is energy which is mainly generated by fossil fuel combustion or by chemical reaction, dumped into the environment in most of the cases, although it may still be used for some useful and economic purposes [2].

Heat can be rejected at virtually any temperature, depending on the process. This can vary from low temperatures chilled water, to high temperatures as that of industrial furnaces, kilns and exhaust stacks. Not necessarily the amount, but its value or quality, is the most important property of heat. The higher the waste heat temperature is, the higher the heat quality will be and therefore the more economic heat recovery process will result.

As waste heat is a valuable source of energy, its efficient recovery, utilization and management will not only help to improve the energy efficiency of any system, but will also contribute to preserve exhaustible natural energy resources (fossil fuels) while at the same time it will lead to the sustainability of our environment through its contribution to the reduction of CO_2 emissions. In addition, it will help to save resources and improve the profitability of any particular process.

1.3 Energy Management:

In most organizations, energy is one of the largest controllable expenses. Reduced energy consumption is likely to lead in lower operating costs for the facility. Thus, energy conservation benefits are reflected directly in the profitability of an organization while also contributing to the improvement of the global environment.

There are growing factors that draw companies' attention to energy efficiency. Such drivers can come from both the company (i.e. top managers, quality issues, processes demand and resources) and from outside (i.e. government regulations market). Nonetheless, the energy efficiency technology applied to any process, regardless of what the factor is almost always the top management decision.

While the strategy for energy management goes beyond this study, the implementation of energy-efficient projects in private sector is very low, and heavily influenced by the priorities of the top managers, capital availability expected payback period, etc.

Having seen the value of energy management in food processing industries in Palestine, it can be inferred that Palestine can be tracked in reducing its CO_2 emissions by introducing energy management strategies in the process industries. This leads us to the title of this research which is: “Thermal Energy Integration of Milk Pasteurization Process Using Pinch Analysis: A Case Study of Al-Junaidi Company for Food and Dairy Products”.

1.4 Aim:

The aim of this thesis is to investigate and develop methodologies for optimum heat recovery from industrial waste streams of a dairy factory, in order to minimize energy consumption and reduce CO_2 emissions. This research will concentrate on analysis of the waste heat recovery in pasteurization process using pinch technology.

1.5 Objectives:

In order to achieve the project aim mentioned above, the following objectives have been adopted in this project:

- To conduct an extensive literature review of the pinch technology in order to reduce energy consumption of the pasteurization process.
- Based on the literature review carried out, to consider the modification of the existing system in order to improve process energy performance developing heat exchangers network based on pinch analysis.
- Based on the data obtained from the above step, to select the heat exchangers that may be used for increasing energy efficiency in the pasteurization section of Al-Junaidi Company.
- To evaluate the reduction in CO_2 emissions per year when implementing the new heat exchanger's network.
- To calculate the annual savings and the payback period of the proposed system and to compare energy cost with current energy consumption.

Chapter 2: Literature Review

2.1 Introduction:

This chapter includes the review of the literature on the state of the art technologies adopted for the application of pinch technology. Four decades ago, the spark that started pinch analysis opened up a new field of intensive research that has expanded in recent years. Pinch Analysis (PA) initially provided a systemic thermodynamic approach to addressing the need for significant energy savings around the oil crises of the 1970s [3]. The Pinch Methodology (PM) has expanded significantly since its conception, seeing practical application to a wide range of industrial, regional and global challenges. Although more awareness is still needed for research communities of the latest updates of the pinch technology, the maximum benefits of pinch technology can be achieved by developing design solutions with an appreciation for the most recent developments. More review of the literature reported in this chapter.

2.2 Literature Review:

In 1971, **Charles Hohmann** presented a doctoral thesis on industrial energy conservation using heat exchange networks. Hohmann stated that the minimum hot and cold utilities required for a process could be computed without knowing the heat exchanger network that may accomplish it.

In 1977, Ph.D. student **Bodo Linnhoff** demonstrated the existence of a heat integration bottleneck, 'the pinch' in many processes, which drew the outlines for the technique (Pinch analysis as known today). Then he led practical application and further improvement of the method at Chemical Industries (ICI).

Bakhtiari et al. (2013) [4], presented a new HEN retrofit design methodology, based on the traditional network pinch approach (NPA). The new procedure provides an effective technique for functional retrofit construction by heat exchangers network (HEN). As a new concept for HEN retrofit design, effluent streams (waste energy) and environment units are introduced. Additional energy savings or reduction of capital cost fot some plants, can be achieved by the flexibilities for target temperatures and the possibility to link a soft target temperature with the supply temperature of another stream are other original. The ability to handle several hot and cold utilities with different costs coupled with the required superstructure helps to move the utility and relocate the utility if necessary. Based on fluid catalytic cracking literature data, the retrofit procedure has been tested. Although this case study did not use some of the new features of the proposed approach, the results obtained are comparable to the designs described.

The increasing cost of traditional fuels and their impact to the environment motivated the necessary for new techniques to reduce energy consumption in industry. Energy auditing techniques are commonly used to increase energy efficiency. **Fenwicks et al. (2014)** [5], used pinch technology analysis, which involves heat exchanger design and retrofits, to optimize energy utilization in thermochemical industries. The application of the pinch technology analysis to a sulphonation process at Orbit Chemical industries Nairobi was presented by this study. The sulphonation process at Orbit Chemicals Industries has theoretical maximum recoverable energy of 0.316 MW, theoretical minimum external heating load requirement of 2.456 MW and a theoretical minimum cooling load of 0.014 MW. The current utilities have 2.772 MW for heating load and 0.329 MW for cooling load. Which means that 96.6 % of the cooling demand and 11.4 % of the heating demand could be saved by implementing the proposed design. 7 heat exchangers, 7 external heating loads and 3 external cooling loads are needed for the proposed design. Implementation of the energy recovery network design was found to cost KShs 49275540 and would enable the company to make savings of KShs 3132093 per year. The simple payback period of the project is 14 years. The retrofit design can be implemented in part or wholly.

High energy cost is the main problem that faces the milk dairy processes. The energy auditing could be a useful method and for milk dairy processes, by energy auditing technique the waste energy can be reduced and the system efficiency can be increased. **Modi. A. and Prajapat R. (2014)** [6], proposed an alternative system to utilize the waste heat of pasteurization process in order to reduce the milk processing energy cost. The proposed system achieved an improvement of 18.6% on pasteurization process load and 2.3% on milk total electricity load. The proposed system layout is shown in Figure 2.1.

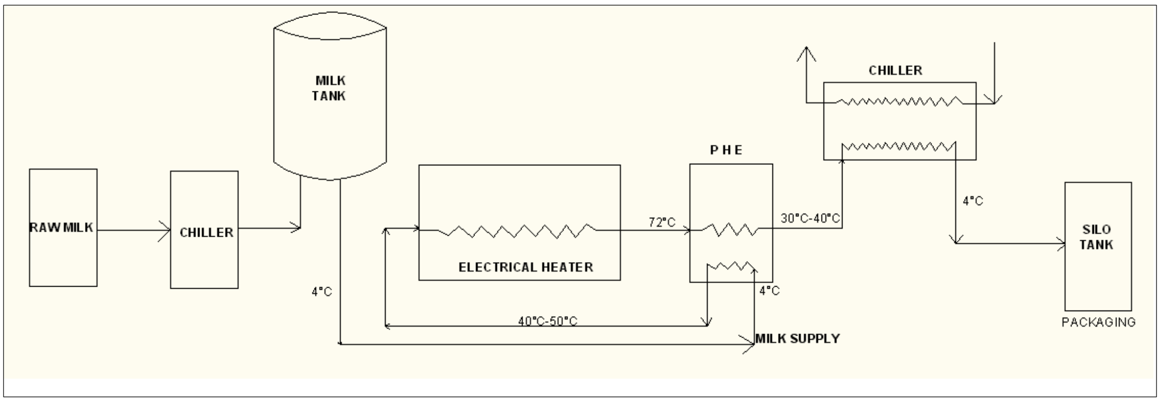


Figure 2.1: Proposed system layout provided by Modi. A. and Prajapat R for milk pasteurization process [6].

In 2014 **El-Temtamy et al.** [7], investigated opportunities for energy conservation in Western Desert Gas Complex (WDGC) through modification of the heat exchanger train. The work achieved great reduction in the utility consumption of a natural gas processing plant (WDGC) by implementing heat exchanger networks synthesis methodology through pinch design technology. New heat exchangers networks was designed for the plant at different values of ΔT_{min} and compared their annualized total cost in order to reach to the optimum one. By comparing the utilities consumption, the optimum ΔT_{min} is 10 ºC, where maximum savings of hot and cold utilities (42 and 21%, respectively). Only two heat exchangers are needed to be added to the existing plant to realize the savings, while the payback period of approximately one year.

A new graphical method has been developed by **Gadalla (2015)** [8], to describe an existing heat exchanger network, including details of exchanger matches, heaters and coolers. Based on pinch analysis principles, the new method can graphically analyze and evaluate the performance of the existing HENs or preheat trains. The new graphical method is capable of offering possible medications for better integration of energy. The method also provides a systematic procedure, graphical-based by which potential modifications can be implemented, see Figure 2.2. A case study of a CDU has shown a high potential for energy savings and emissions reduction. The results showed that 17% in energy savings and 39% in cooling water demands are achieved by the new HEN. Commercial simulators for energy analysis (e.g. Aspen Energy Analyzer) could be replaced by the new method because it provides an interactive visualization of the HEN analysis. In fact, the new graphic technique allows to better understand the energy analysis issue and the practices in energy integration. It also enables the graphical shifting of heat between exchanger loops and the reduction of heat of resources by using utility paths.

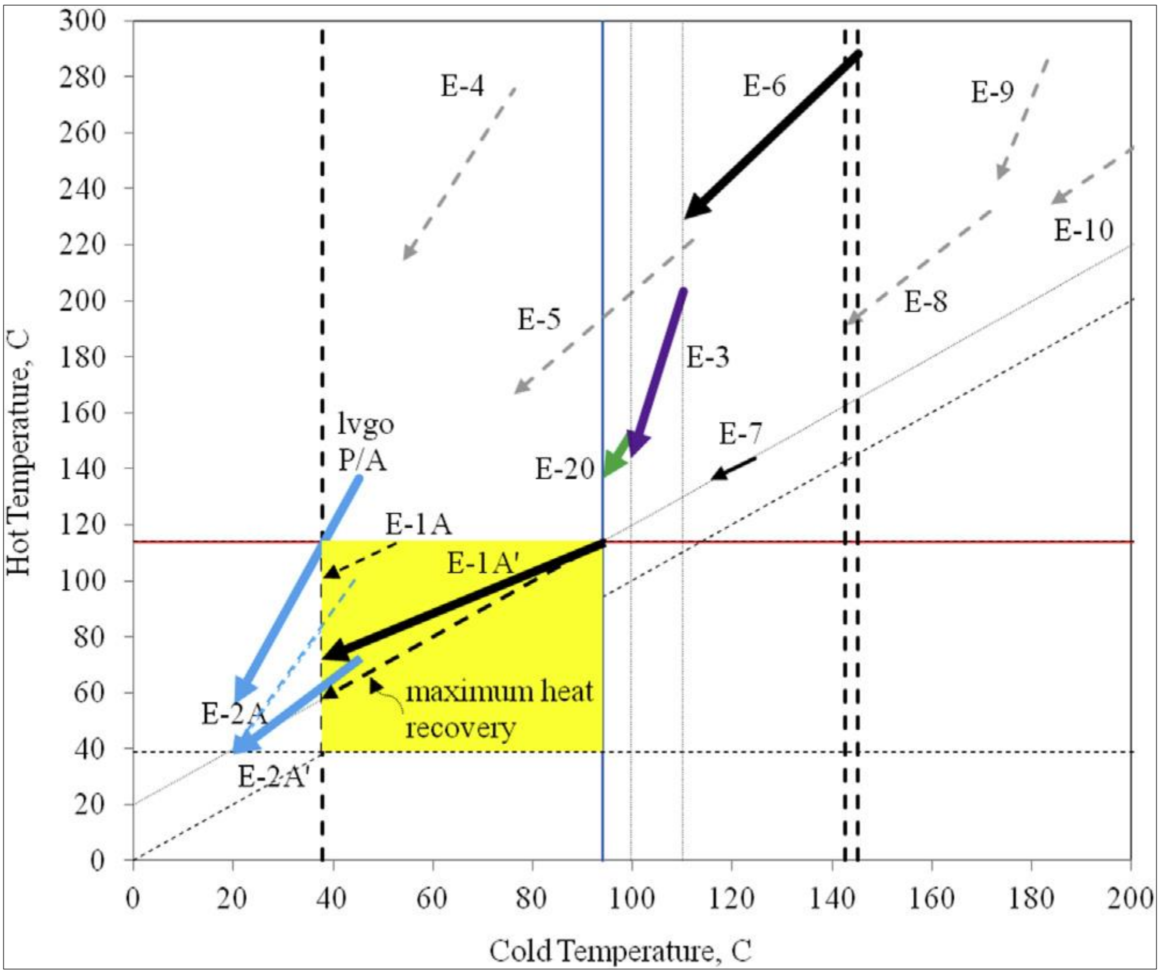


Figure 2.2: A new graphical procedure for heat exchanger network modifications developed by Gadalla [8].

Walmsley et al. (2016) [9], developed a new ultra-low energy evaporation system design. The Grand Composite Curve was used to identify process modifications and the appropriate placements of vapor recompression so to reduce energy consumption. Actually, the additional use of mechanical vapor recompression in the device releases significant energy, cost, and emissions savings. The proposed design saves 78% of steam (6397 kW) with expense of 16% (364 kW) more electricity use. The new design is estimated to save $942,601/y and the emissions will be reduced to 3416 t CO_2-e/y. Due to increased Total Site Heat Integration, more improvements in energy efficiency are achieved by recovering heat from the dryer exhaust air and boiler condensate return streams.

Ethylene oxide production process is considered a significant energy consumer in chemical industry, and therefore even a slight improvement in its overall efficiency can have a considerable impact on the sustainability of the process. **Ghannadzadeh et al. (2017)** [10], stated that efficiency improvement can be carried out using the exergy-aided pinch analysis. Results indicated that by inspecting streams by combined methodology the minimum cold utility demand could be reduced from 601.64 MW (obtained by standard pinch analysis) to 577.82 MW.

Umar et al. (2017) [11], used the pinch analysis to minimize energy consumption of a process plant by maximizing the utilization of hot and cold utilities available within the process. Savannah Sugar Company's energy integration was conducted using 7 ° C as a minimum temperature difference and the following results were drawn. The temperature interval cascade, and composite curve diagrams were developed based on data from Savannah Sugar Company's operating manual. The hot and cold utilities requirements and pinch point were determined. The hot utility requirement, cold utility requirement and pinch point were calculated to be 2120 kW, 45500 kW and 114.5°C, respectively from the temperature interval, cascade and hot and cold composite curves. The heat exchanger network was designed for maximum heat recovery and minimum utility consumption and 1138 kW (34.9%) and 56893 kW (55.6%) were recovered from the requirements for hot and cold utility.

Integration process using Pinch method was applied in building engineering systems by **Misevičiūtė et al. (2017)** [12]**.** Study has shown that values close to 5 ° C for process integration in ventilation units should be chosen, i.e. they should be below the recommended minimum temperature difference of 15 ° C for industrial systems. The analysis of energy and exergy requirements before and after process integration reveals that the need for seasonal energy in the non-integrated system is 26% higher, whereas the need for seasonal exergy in the non-integrated system is 45%b higher than in the integrated system.

Li et al. (2019) [13], developed a new graphical tool of T–H diagram which helps to identify the exact crossing pinch load involving phase change clearly. A systematic and practical pinch analysis based retrofit approach is proposed in this study to eliminate those crossing pinch exchangers as a whole rather than one by one, for any existing industrial HEN. A case study of crude oil preheat train (COPT) are adopted to demonstrate the effectiveness of the proposed new approach. The new T – H diagram visualization tool will accurately determine the exact positive or negative cross-pinch load of these exchangers with phase change and varied heat capacity flowrates (FCs). The suggested retrofitting approach based on PA is practical and effective in retrofitting any COPT with several pinches, varying FCs and large scale. The energy saving percentage obtained by applying the suggested retrofit solution rises from the reported value of 45–75%.

Chapter 3: Pinch Analysis

3.1 Introduction:

There are many methods to improve energy efficiency. The main pillars to determine the most efficient use of energy are researching energy management, energy conversion, energy recovery, and system optimization.

Energy management is the easiest way to reduce energy use. Turning off lights when they are not needed and being aware of power use in general are simple ways of controlling energy. Energy conversion includes analyzing the choice of a fuel as an energy source and the most effective use for an application of that fuel. The target of energy recovery is to reduce losses and waste energy. Different methods to recover the power can be considered. Commonly applied strategies include increasing insulation, preventing friction and restoring heat by heat exchange. Indirect heat exchangers are most used for liquids, while heat pumps are often used for air. Process integration or pinch analysis is a way of quantifying the maximum potential for an industrial process to recover energy [14]. Energy management and process integration are the most relevant points for this research.

3.2 Pinch Technology:

Pinch analysis is a technique to reduce the energy consumption for chemical processes by estimating and meeting thermodynamically realistic energy goals by maximizing heat recovery systems, methods of energy supply and operating conditions. It is also known as energy integration, process integration, heat integration or pinch technology.

It is based on thermodynamic theories and the fact that different processes need specific temperatures and pressures in an industrial plant. It is a method for developing a heat exchanger network and exploring solutions for heat and power utilities.

As a function of heat load against temperature, the process data is represented as a set of energy flows or streams. These details were combined to give composite curves for all flows in the plant one for all hot streams (releasing heat) and one for all cold streams (requiring heat). The pinch temperature is the point of closest approach between the hot and cold composite curves and is where the design of the heat exchanger network is most constrained. Thus, the energy targets can be reached using heat exchangers to recover heat between hot and cold streams by finding this point and starting designing there. In practice, during the pinch analysis, there is often a cross-pinch heat exchange between a stream with a temperature above the pinch and one below the pinch. The removal of these exchanges by alternative matching enables the process to reach its energy target.

The main advantage of process integration is to recognize a system as a whole to enhance its design and/or operation (i.e. integrated or holistic approach). By contrast, an analytical approach would attempt to separately improve or optimize process units without necessarily exploiting potential interactions between them.

In many fields and industries, pinch technology can be applied, particularly those that depend on thermal operations. Wherever energy is used, this innovation has a potential opportunity. It can also be implemented successfully in the petrochemical and chemical engineering mainstreams. Processes for heating and cooling are another field relevant.

There are a few important concepts to be identified in order to understand the fundamentals of pinch technology: hot and cold streams, heat exchangers, heaters, coolers, composite curves, minimum temperature difference, the pinch, interval temperatures and grand composite curves.

A ***hot stream*** is a stream of fluid with a specified flow and heat capacity that needs cooling to adjust its temperature from an original to a target value. A hot stream means a need for cooling. Likewise a cold stream needs heat to change the temperature from the initial value to the target value. A cold stream means a need for heating.

There are three types of heat exchangers used in pinch technology: An ***internal heat exchanger*** to transfer heat between hot and cold streams, ***heaters*** that add heat to the cold stream from an external heat source when external heating is needed. The external heater is called a ***hot utility*** and ***coolers*** that extract heat from the hog streams to an external cooling system. The external cooler is called a ***cold utility***.

The ***minimum temperature approach*** ΔT_{min}, is the lowest temperature difference that can be accepted in a heat exchanger between the hot stream and the cold stream. The value of ΔT_{min} is determined by economic consideration, the smaller ΔT_{min} reduces the external heaters and coolers. On the other hand the internal heat exchanger area will increase, which also increases the capital cost, due to the low driving force [14].

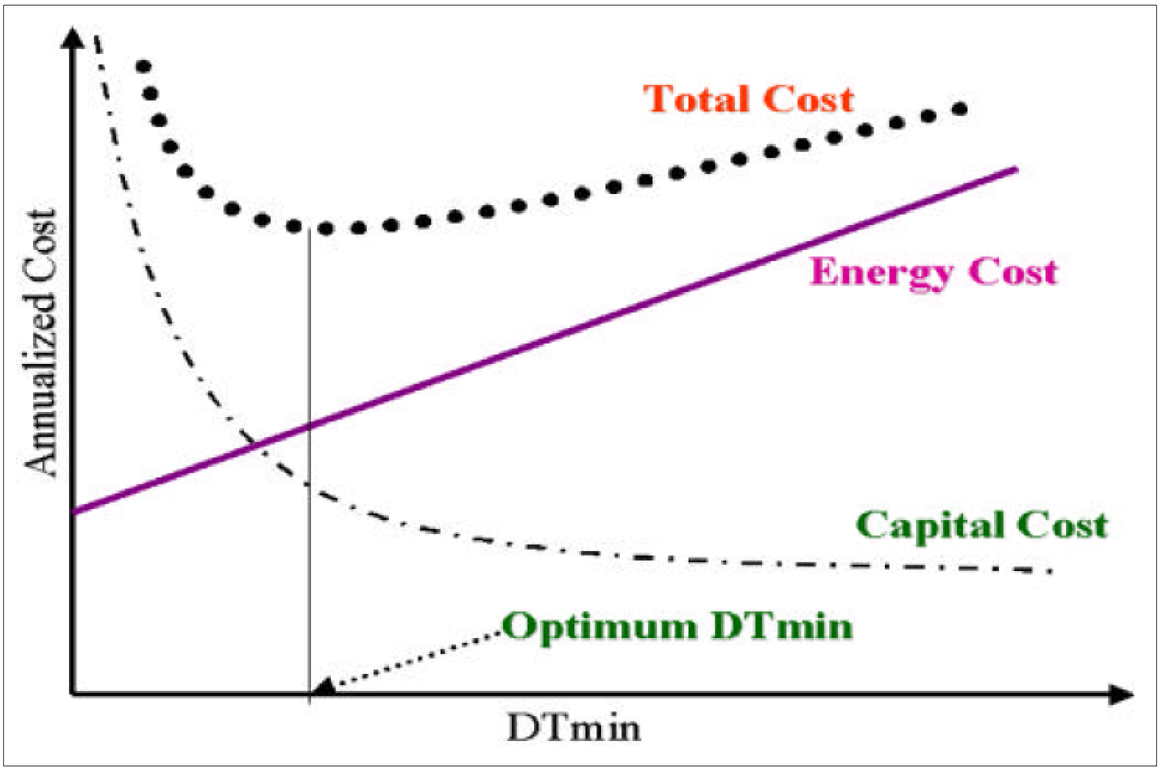


Figure 3.1: Annual costs as functions of minimum temperature approach [15]

Composite curves are helpful in establishing multi-stream energy targets. The hot composite curve is developed by determining the total heat content over any specified temperature range of all known hot streams. Correspondingly, the cold composite curve is built. Where the two curves overlap, it is possible to exchange internal heat; heat can be transferred from the hot to the cold streams. If the two curves do not overlap each other, it is necessary to use additional heating or cooling.

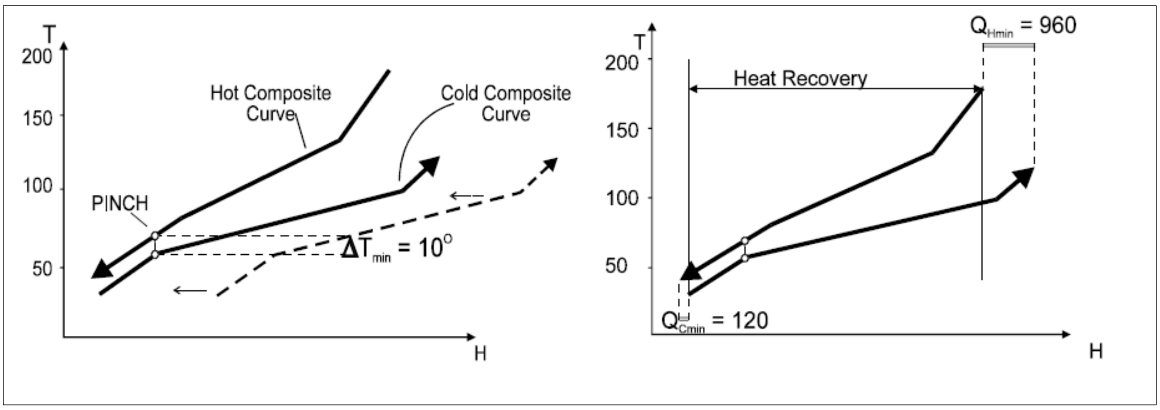


Figure 3.2: Using the hot and cold composite curves to determine the energy targets [16]

The pinch temperature usually only occurs at one point with the minimum allowable temperature difference between hot and cold streams. Cooling above the pinch means extracting energy from a system that has a heat deficit. Therefore, the same amount of heat must be added to the external heater. Heating below the pinch means adding energy to a system that already has a heat excess. It is therefore necessary to remove the same amount of heat with external coolers.
So it is possible to identify three golden rules [17]:
• Heat transfer through the pinch is not permitted;
• Cooling with external coolers is not allowable above the pinch;
• Heating with external heaters is not allowable below the pinch.

Interval temperatures are obtained by removing ½ ΔT_{min} from the hot stream temperatures and adding ½ ΔT_{min} to the temperature of the cold stream. In interval temperatures, the minimum approach temperature difference will then be zero. If in a given temperature interval there is an excess of heat this can of course be used to cover a deficit at a lower temperature interval, as the hot streams in this interval are hot enough to supply a deficit in the cold streams at lower temperature intervals.

The composite curves are not particularly useful when selecting utilities to be used, determining utility temperatures, and deciding on utility requirements. In 1982, Itoh, Shuroko and Umeda introduced a new method, ***the grand composite curve (GCC)***. The GCC demonstrates the heat supply and demand variation within the system. This diagram can be used to figure out which utilities to use. The aim is to maximize the use of the cheaper utility levels and minimize the use of the expensive utility levels. Instead of high pressure steam and refrigeration, low pressure steam and cooling water are preferred.

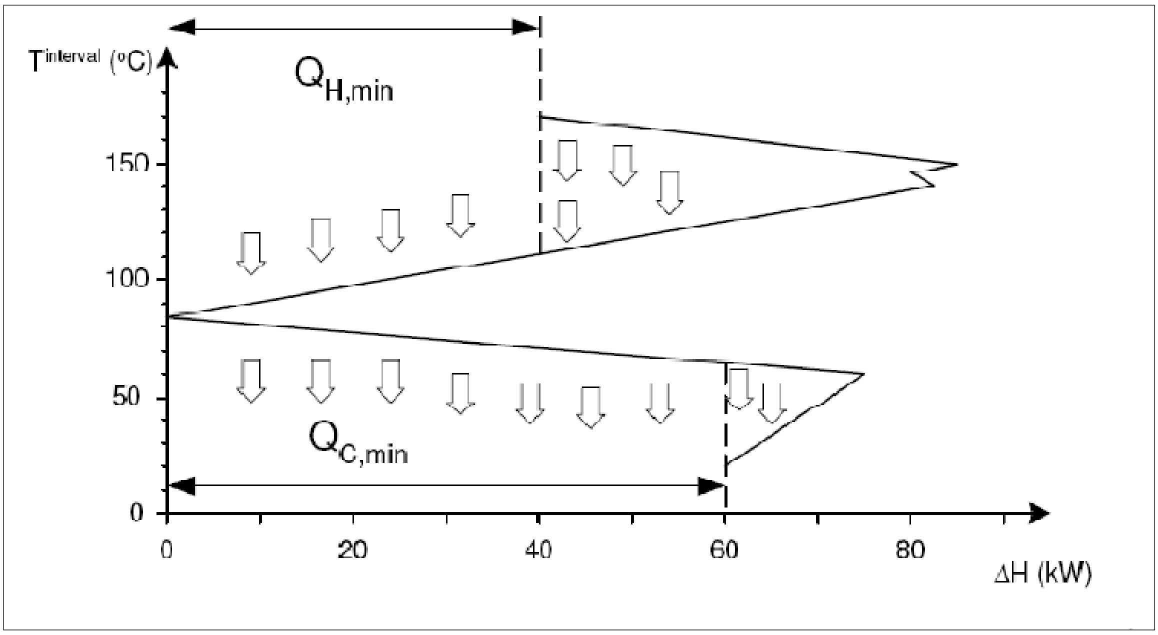


Figure 3.3: A grand composite curve [18].

In summary, the grand composite curve provides considerable and important information for the engineer that can be applied in the design of heat exchanger networks with minimum energy consumption [18]: The minimum energy consumption can be calculated on the basis of the actual data and the specified value for ΔT_{min}. In the cascade where the heat flow is zero, the process pinch point can be identified as the location. This is also the temperature region of where the driving forces are at their minimum. The pinch point splits the process into two separate parts, one region with a heat deficiency and one region with a heat surplus. Minimum energy consumption can only be achieved by designing the heat exchanger network according to the following rules:

- Heat transfer through the pinch is not permitted;
- Cooling with external coolers is not allowable above the pinch;
- Heating with external heaters is not allowable below the pinch.

3.3 Steps of Analysis:

First of all, we need to consider the energy recovery system. Identify streams and existing links to the heat exchange. Such streams must be categorized as hot streams and cold streams and recording their required start and target temperatures. The thermal properties of these streams and the mass flow rate can be defined as:

$$F_{cp} = cp \times \dot{M} \quad (1)$$

Where $\dot{M}$ is mass flow rate in kg/s and cp is specific heat in J/kg·K. Although there are different levels of pressure in some processing equipment in this analysis, the material never changes phase and the pressure of the streams between equipment is about the same, so cp is assumed to be constant.

The amount of heat transferred from the hot stream to the cold stream is called the duty of a heat exchanger. When no phase change, the heat duty is given by:

$$Q = \Delta T \times F_{cp} \quad (2)$$

were Q is the duty in watts and ΔT is the temperature difference between the inlet and the outlet of heat exchanger.

The above information should be determined in a stream data table to identify the available heat and needed in heat exchangers network. The minimum allowable temperature difference between the streams affects the design of heat exchangers. It is also critical to choose the optimal value of ΔT_{min}.

This study aims to analyze energy saving potential and apply pinch technology for pasteurization process of milk at Al-Junaidi Company for Food and Dairy Products.

3.4 A case study - Al-Junaidi Company for Food and Dairy Products:

Al-Junaidi Company for Dairy and Food Products was established in 1982 in Hebron-Palestine. Since its establishment, it has been grew to be the leader of dairy products producers in Palestine. The daily production capacity of the main production lines totals to a minimum of (100,000 - 110,000) liters of fresh milk in addition to (30 tons) of fresh salads, (7 tons) of snacks, and about (35,000) liters of long term juice and drinks. The study will concentrate on the pasteurization process of three milk pasteurizers, with a total flow rate of 21000 liter per hour in the peak period.

Pasteurization is the heating phase of a fluid to kill microorganisms below the boiling point. It was developed in 1864 by Louis Pasteur to improve wine keeping qualities [19]. Commercial pasteurization of milk started in Europe in the late 1800s and in the early 1900s in the United States. In 1908, pasteurization became mandatory for all dairy produced in the city of Chicago, and in 1947 Michigan became the first state to allow pasteurization of all milk for sale in the state. Pasteurization typically uses the cycle of heating and cooling above the boiling point of milk and above the freezing point. When civilization grew around the turn of the 20th century, increased dairy production and distribution led to milk disease outbreaks. In combination with improved management practices on dairy farms, these diseases were virtually eliminated with the commercial implementation of pasteurization. Milk products were the cause of 25% of all food and waterborne diseases linked to origins in 1938, but now they account for much less than 1% of all food and waterborne diseases [20]. Pasteurized milk process is a regular process that needs large amounts of electricity and fuel consumption. Pasteurization aims:

• To increase milk safety for the consumer by destroying disease causing microorganisms (pathogens) that may be present in milk such as viruses and harmful organisms such as bacteria, protozoa, moulds and yeasts

• To increase keeping the quality of milk products by destroying spoilage microorganisms and enzymes that contributes to the reduced quality and shelf-life of milk. [21]

The analysis procedure for the three pasteurizers is described in more detail to illustrate the methodology.

Data was collected together with Al-Jinaidi company staff. The energy streams were compiled and characterized as hot or cold streams. The cold and hot streams, are shown in Table 3.1.

Table 3.1: Hot and cold streams identified from the pasteurizers.

Stream No.	Material	Supply Temp. [C]	Target Temp. [C]	Flow rate [L/h]
1	Milk	5	95	8000
2	Fresh Milk	10	95	10000
3	Milk	15	95	3000
4	Milk	95	10	8000
5	Fresh Milk	95	20	10000
6	Milk	95	37	3000

In order to deal with previous data, the thermal specification of milk streams should be identified. The mass flow rate of the streams can be determined if the density of the fluid and the volume flow rate are known, the following equation can be used to find *mass flow rate ($\dot{M}$) in kg/s* of the streams:

$$\dot{M} = \dot{V} \times \rho \quad (3)$$

where $\dot{V}$ is the volume flow rate in m^3/s and ρ is the density in kg/m^3 . In addition to the density of the fluid, it is also necessary to know the specific heat capacity. Table 3.2 shows the specifications of milk according to the quality unit in Al-Junaidi Company:

Table 3.2: Milk and fresh milk properties.

Material	$cp\ [\frac{kJ}{kg}.K]$	$\rho\ [\frac{kg}{m^3}]$
Milk	3.94	1030
Fresh Milk	3.94	1030

When using the pinch technology, it is important to determine the ***heat capacity flow rate F_{cp},*** which represents the quantity of heat that flowing in the stream. The heat capacity flow rate (in kW/K) is given by:

$$F_{cp} = cp \times \dot{M} \quad (4)$$

while the heat content of a stream can be found by multiplying the heat capacity flow rate by the temperature difference between the start point temperature and the target temperature of the stream. The streams data are summarized in Table 3.3:

Table 3.3: Hot and cold streams data after calculating the required parameters.

No.	Material	H/C	Supply Temp. [C]	Target Temp. [C]	$\dot{V}$[L/h]	$\dot{M}$[kg/s]	Fcp [kW/K]	ΔH [kW]
1	Milk	Cold	5	95	8000	2.289	9.018	811.6
2	Milk	Cold	10	95	10000	2.861	11.273	958
3	Fresh Milk	Cold	15	95	3000	0.833	3.283	262.6
4	Milk	Hot	95	10	8000	2.289	9.018	766.5
5	Milk	Hot	95	20	10000	2.861	11.273	845.4
6	Fresh Milk	Hot	95	37	3000	0.833	3.283	190.4

The above mentioned data are enough to start the analysis, but before the start the minimum temperature difference should be determined. Several recommendations on how to choose the minimal temperature difference are listed in [22] and [23]. The first approach is focused on the physical state of the streams whereas the second model is based on the type of processes involved in the streams. With respect to the physical condition of the streams Kemp [17] recommends using the following minimum differences in temperature: 10°C, 15°C and 20°C for liquid, liquid/gas and gas streams, respectively. Thus shifted temperatures for the streams are obtained, determined in accordance with the following equation:

$$T_n = T_n \pm \frac{\Delta T_{min}}{2}$$

Due to the use of liquid streams, the shifted supply and target temperatures were obtained by selecting the minimum temperature difference of 10 ° C. The shifted temperatures of hot and cold streams are shown in table 3.4.

Table 3.4: Shifted hot and cold streams.

No.	**Material**	**H/C**	**Supply Temp. [C]**	**Target Temp. [C]**	**Fcp [kW/K]**	**ΔH [kW]**
1	Milk	Cold	10	100	9.018	811
2	Milk	Cold	15	100	11.273	958
3	Fresh Milk	Cold	20	100	3.283	262.6
4	Milk	Hot	90	5	9.018	766.5
5	Milk	Hot	90	15	11.273	845.4
6	Fresh Milk	Hot	90	32	3.283	190.4

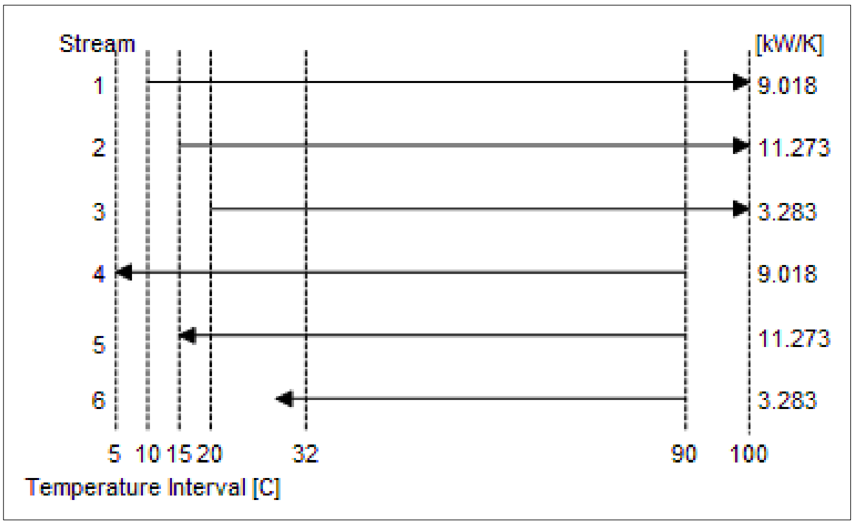


Figure 3.4: Identification of temperature intervals

Temperature intervals are described in the figure 3.4, where the number of streams within the interval is constant. Therefore, there are interval limits where the stream starts or ends. Note that, in fact, the hot streams within each interval are hotter than the cold streams by just ΔT_{min}, which means that heat is allowed to exchange between them.

However, the heating and cooling demands are seldom matched within each interval. We therefore need to calculate in these intervals the heat excess or heat deficit as follows:

$$\Delta H = \left(\sum (F_{cp})_{Hot} - \sum (F_{cp})_{Cold}\right) \times \Delta T_{interval} \quad (5)$$

Temp. Interval	$\sum (\boldsymbol{F_{cp}})_{\boldsymbol{Hot}} - \sum (\boldsymbol{F_{cp}})_{\boldsymbol{Cold}}$		**Heat Excess/Deficit**
100-90	0 - (9.018+11.273+3.283) =	**23.574**	-235.7
90-32	(9.018+11.273+3.283) - (9.018+11.273+3.283) =	**0**	0
32-20	(9.018+11.273) - (9.018+11.273+3.283) =	**-3.283**	-39.4
20-15	(9.018+11.273) - (9.018+11.273) =	**0**	0
15-10	(9.018) - (9.018) =	**0**	0
10-5	(9.018) - (0) =	**9.018**	45

According to the composite curves, the pinch temperature can be between 10 to 20°C, and the minimum hot and cold utilities can also be read easily from the composite curves, see Figures 3.5, 3.6 and 3.7.

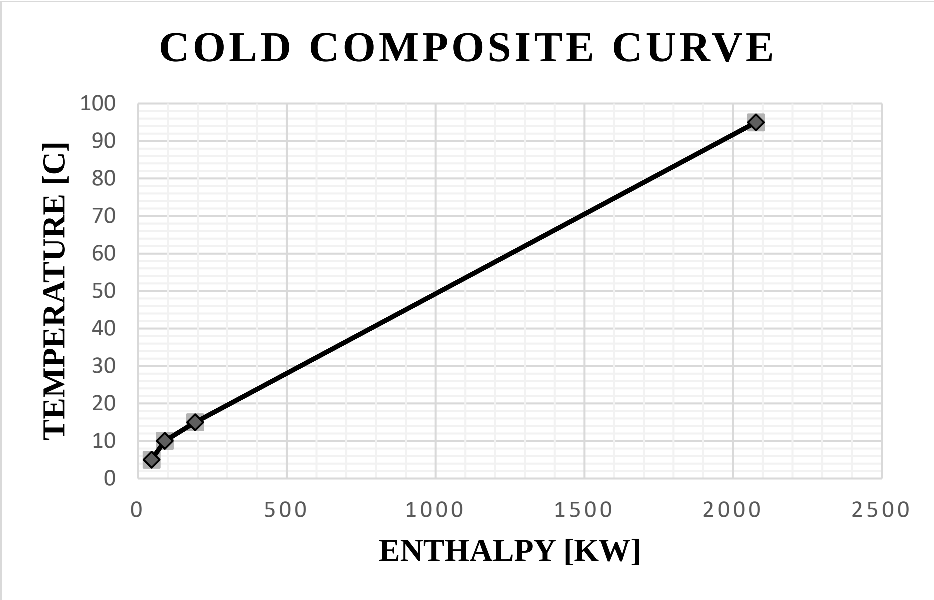


Figure 3.5: Cold Composite Curve

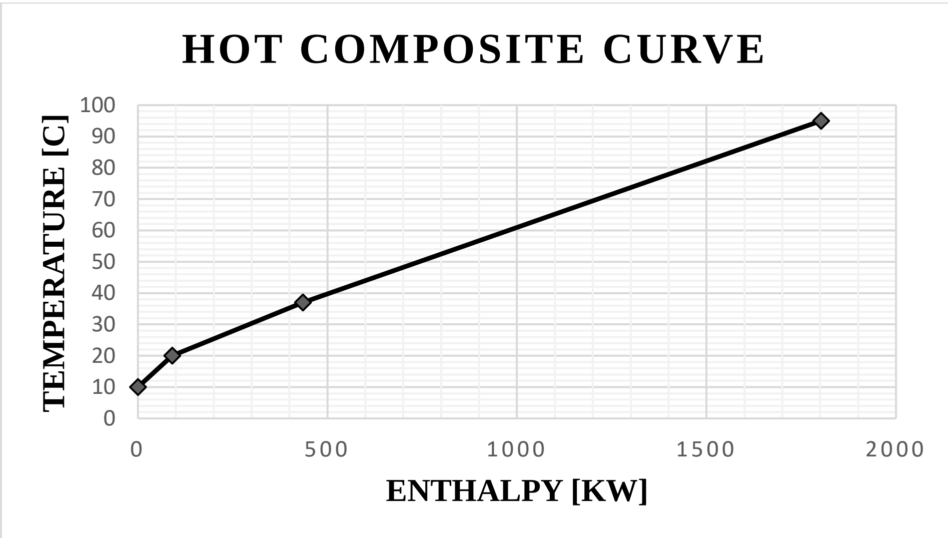


Figure 3.6: Hot Composite Curve

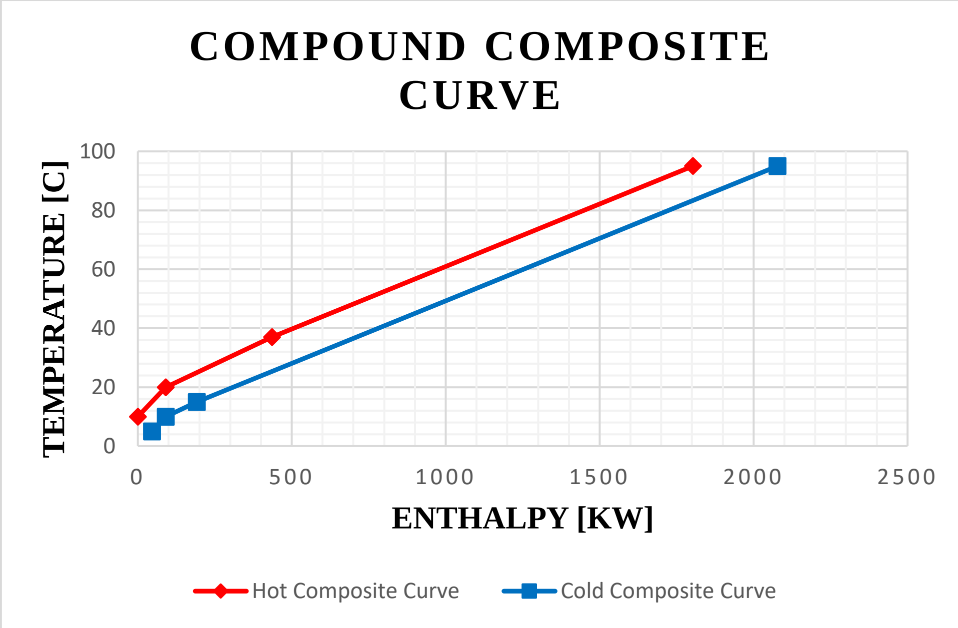


Figure 3.7: Compound Composite Curve

The grand composite curve is a graphical method to determine the pinch, it can be obtained by drawing the hot and cold streams and shifting their position vertically regarding to the y axis until the minimal distance between them according to the selected minimal temperature difference. The temperature modification was used to draw the grand composite curve, see Figure 3.8.

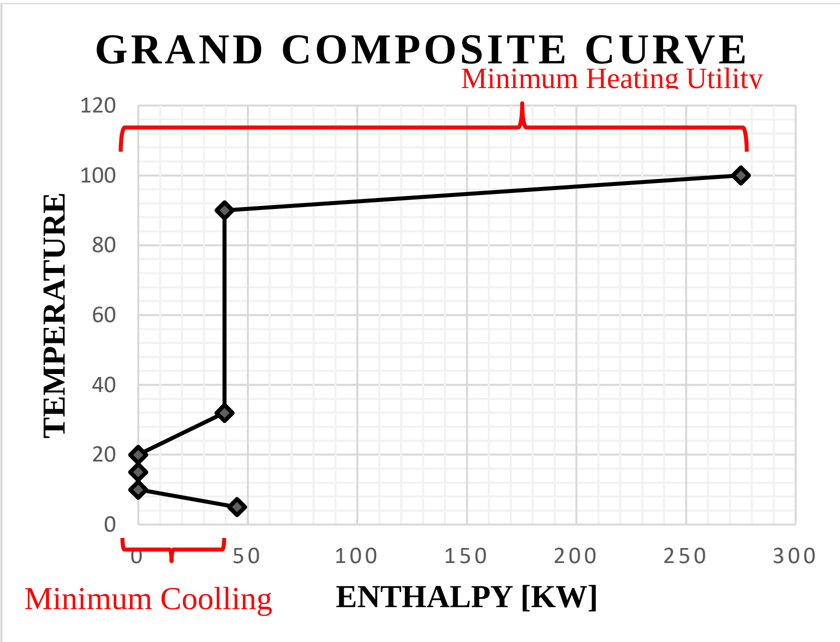


Figure 3.8: Grand Composite Curve

If we have an excess of heat in an interval, this can of course be used to cover a deficit in a lower temperature interval, since the hot streams in this interval are hot enough to supply a deficit in the cold streams in lower temperature intervals. We can thus cascade surplus heat down the temperature scale from interval to interval.

As can be seen in the heat cascade a negative heat flow between two temperature intervals is achieved. This is thermodynamically infeasible since this would mean that heat flows from a lower to a higher temperature. To make the cascade feasible, sufficient heat must be added to make the heat flows at least zero.

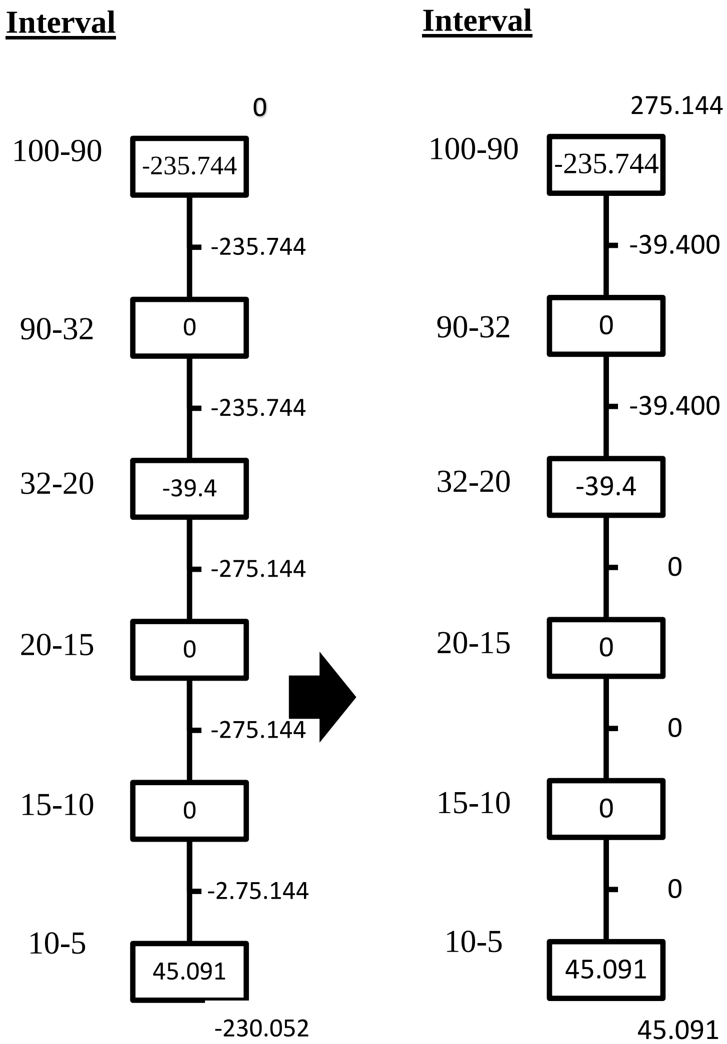


Figure 3.9: Heat Cascade

3.5 Analysis above the Pinch:

The rule is $(F_{cp})_{Hot} < (F_{cp})_{Cold}$. There all only one chance to match all the streams. The streams are represented graphically in Figure 3.10. The enthalpy of each stream should be determined, hot and cold streams can be matched together according to the enthalpy of each stream. A hot stream with high enthalpy would be matched to a cold stream with high enthalpy. As seen in Figure 3.10, each hot stream has the same heat capacity flow rate to a cold stream, the maximum heat recovery can be achieved by matching these streams together. Stream 1 would be matched to stream 4, stream 2 would be matched to stream 5 and stream 3 would be matched with stream 6.

For streams 1&4:

$$Q_1 = \Delta T \times F_{cp} = (95 - 15) \times 9.018 = 721.458 \; kW$$

The outlet temperature of the unticked off streams can be calculated using the following relation:

$$T_{out} = T_{in} + \frac{Q_n}{F_{cp}} \quad (6)$$

$$T_{out} = 15 + \frac{631.276}{9.018} = 85 \; C$$

$$Q_4 = \Delta T \times F_{cp} = (95 - 25) \times 9.018 = 631.276 \; kW$$

$$Q_H = Q_1 - Q_4 = 721.458 - 631.276 = 90.182 \; kW$$

Stream 4 contains smaller amount of heat and it will therefore ticked off. The heat exchanger will transfer 631.276 kW.

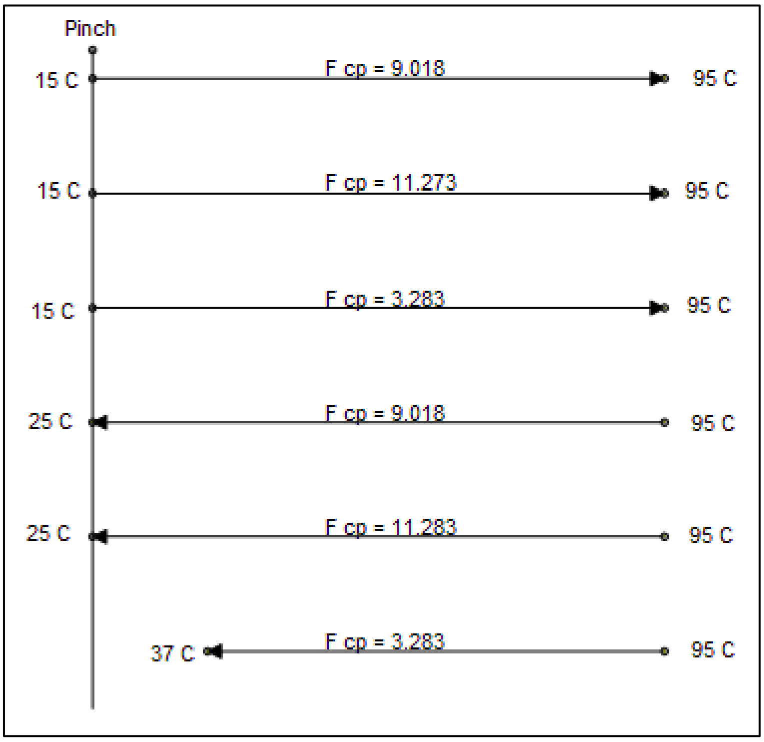


Figure 3.10: Hot and cold streams above the pinch

For streams 2&5:

$$Q_2 = \Delta T \times F_{cp} = (95 - 15) \times 11.273 = 901.823\ kW$$

$$T_{out} = 15 + \frac{789.095}{11.273} = 85\ C$$

$$Q_5 = \Delta T \times F_{cp} = (95 - 25) \times 11.273 = 789.095\ kW$$

$$Q_H = Q_2 - Q_5 = 901.823 - 789.095 = 112.728\ kW$$

Stream 5 contains smaller amount of heat and it will therefore ticked off. The heat exchanger will transfer 789.095 kW.

For streams 3&6:

$$Q_3 = \Delta T \times F_{cp} = (95 - 15) \times 3.282 = 262.667\ kW$$

$$T_{out} = 15 + \frac{190.433}{3.282} = 73\ C$$

$$Q_6 = \Delta T \times F_{cp} = (95 - 37) \times 3.282 = 190.433\ kW$$

$$Q_H = Q_3 - Q_6 = 262.667 - 190.433 = 72.233\ kW$$

Stream 6 contains smaller amount of heat and it will therefore ticked off. The heat exchanger will transfer 190.433 kW.

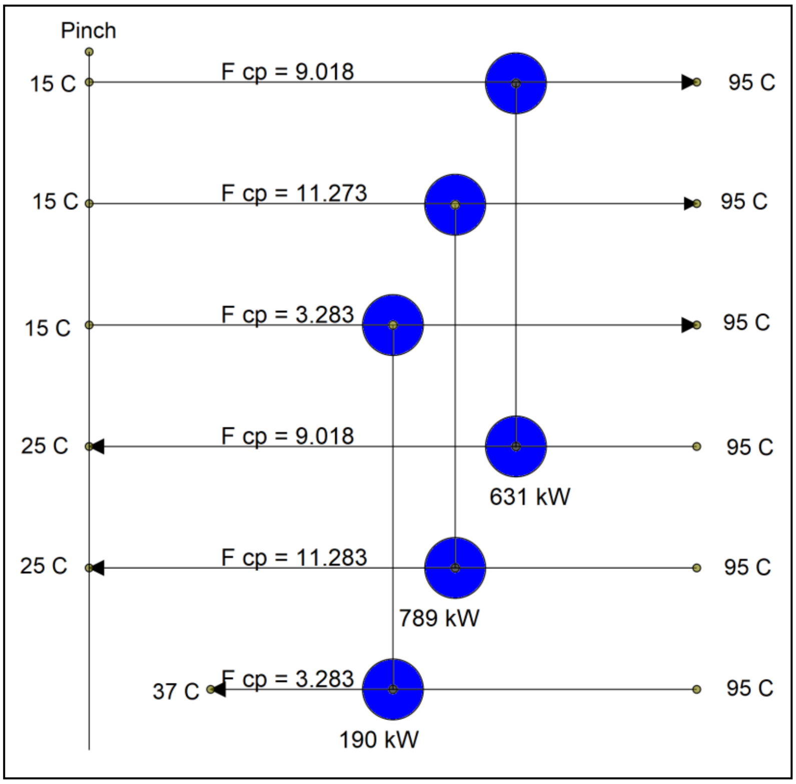


Figure 3.11: Heat exchangers network above the pinch

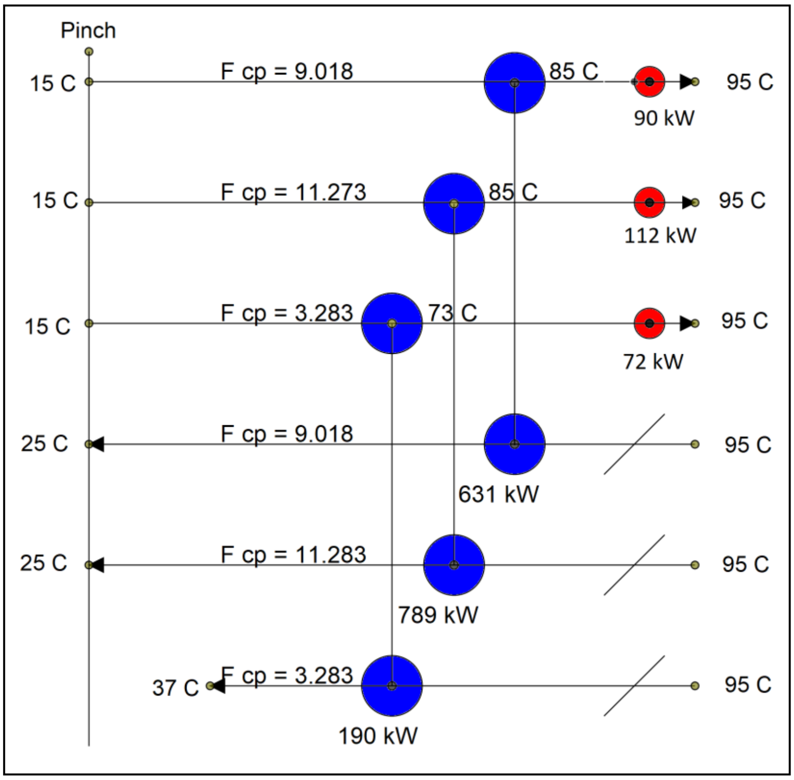


Figure 3.12: Heat exchangers network above the pinch with external heaters.

3.6 Analysis below the Pinch:

The rule is $(F_{cp})_{Cold} < (F_{cp})_{Hot}$. The streams are represented graphically in Figure 3.13. As mentioned before, Stream 1 would be matched to stream 4 and stream 2 would be matched to stream 5, while stream 3 and stream 6 will not appear below the pinch.

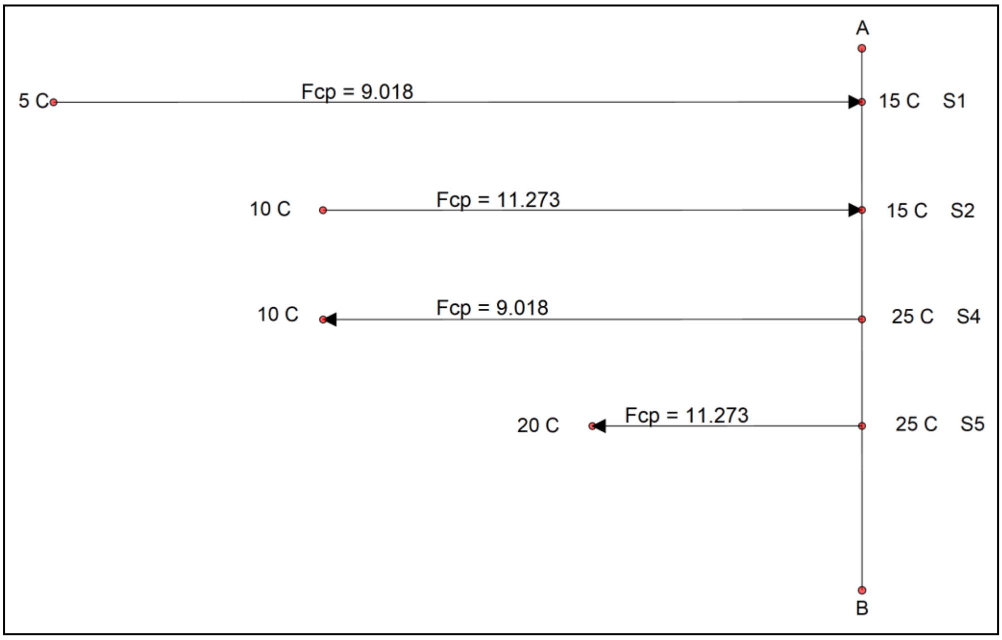


Figure 3.13: Hot and cold streams below the pinch

Streams 1&4:

$$Q_1 = \Delta T \times F_{cp} = (15 - 5) \times 9.018 = 90.182\ kW$$

$$T_{out} = 25 - \frac{90.182}{9.018} = 15\ C$$

The target temperature of stream 4 is equal to the target temperature of stream 1. There are no heat exchange available due to thermodynamic limitations.

Streams 2&5:

$$Q_2 = \Delta T \times F_{cp} = (15 - 10) \times 11.273 = 56.364\ kW$$

$$Q_5 = \Delta T \times F_{cp} = (25 - 20) \times 11.273 = 56.364\ kW$$

$$Q_H = Q_5 - Q_2 = 56.364 - 56.364 = 0\ kW$$

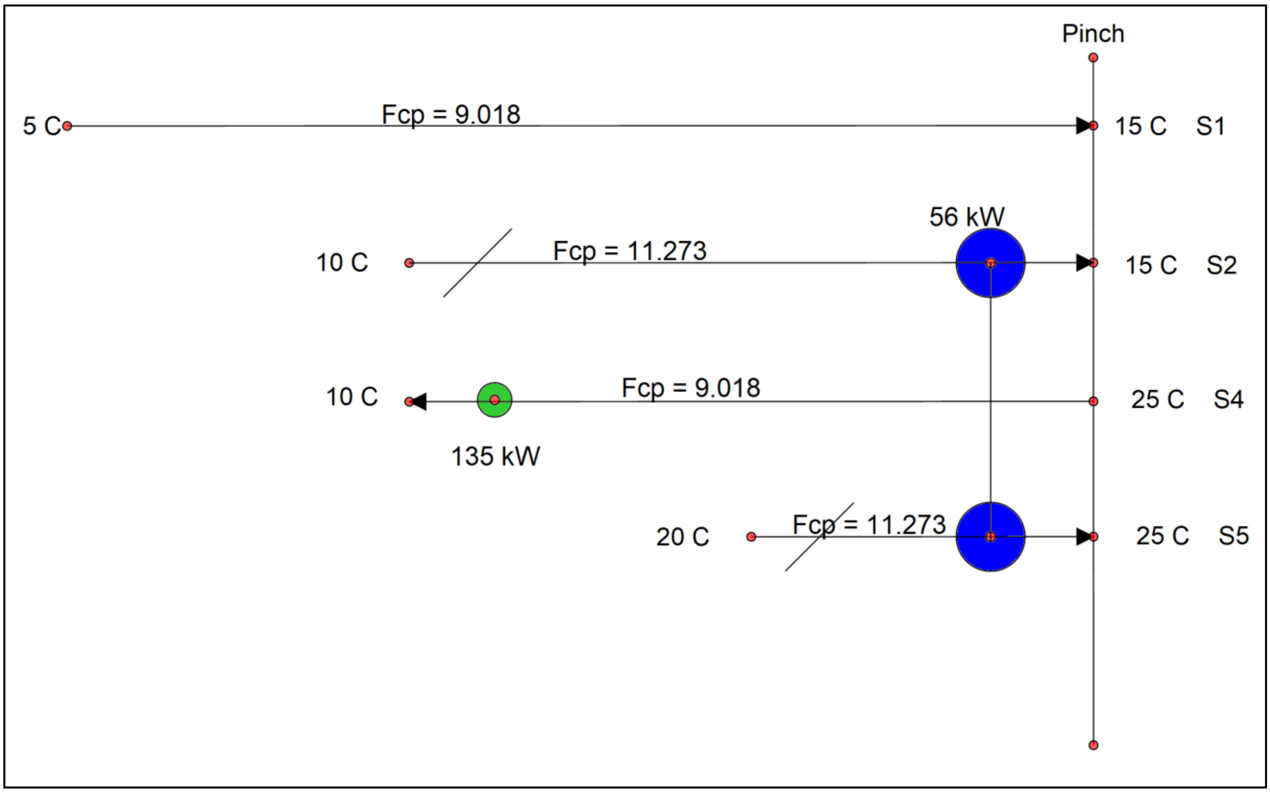


Figure 3.14: Heat exchangers network below the pinch with external coolers.

Stream 2 and stream 5 contains equal amount of heat and they will therefore ticked off. No external heat exchanger is needed.

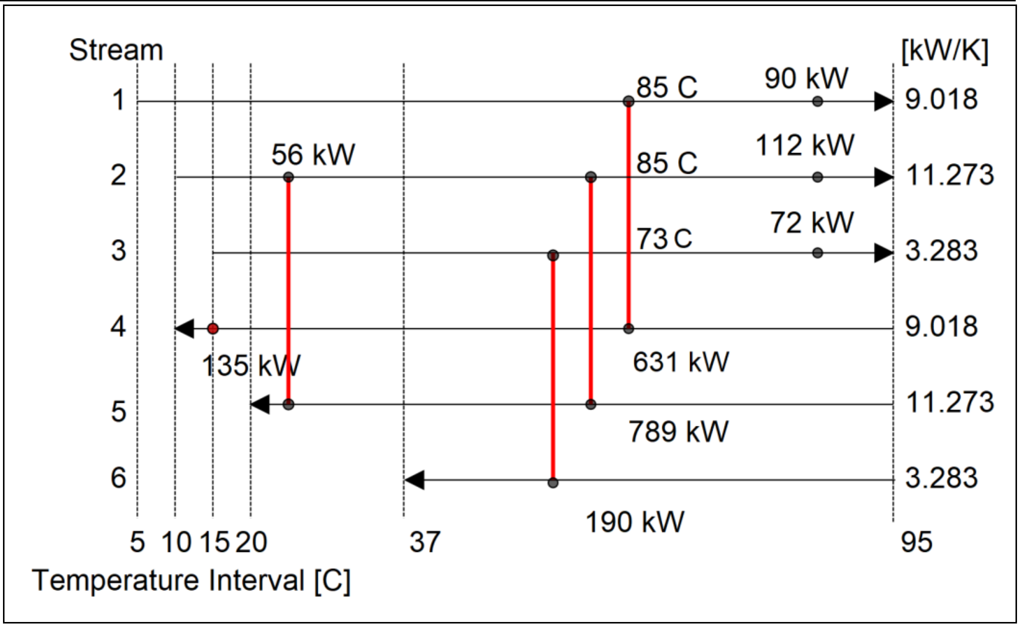


Figure 3.15: Heat exchangers network diagram.

Total heating load before the application of pinch analysis was 2032 kW. Total external heating load provided for by the network is 275 kW, while the remaining amount will be covered through internal heat exchange with the hot streams. The actual external heating load should be increased due to losses. Total cooling load before the application of pinch analysis was 1802 kW. Total external cooling load in the exchange network is 135 kW, while the remaining amount will be covered through internal heat exchange with the cold streams. The actual external cooling load should be increased due to losses [11]. The selection of internal heat exchangers will be discussed in details in the next chapter, while the external cooling and heating demands will be provided through the previous heating and cooling systems before applying the analysis.

Chapter 4: Selection of Heat Exchangers

1.1 Introduction:

Heat exchangers loads, inlet temperature, outlet temperature and flow rate were determined in the previous chapter. The main objective of this chapter is to select the suitable heat exchangers for the heat exchangers network according to the specified parameters. Heat exchangers are typically classified according to flow arrangement and type of construction. The simplest heat exchanger is one for which the hot and cold fluids move in the same or opposite directions, this type heat exchanger usually classified to parallel flow heat exchanger and counter flow heat exchanger. This heat exchanger consists of two concentric pipes of different diameters. In the parallel-flow arrangement, the hot and cold fluids enter at the same end, flow in the same direction, and leave at the same end. In the counter-flow arrangement, the fluids enter at opposite ends, flow in opposite directions, and leave at opposite ends. [28]

Heat exchangers are therefore also classified as Double pipe heat exchangers, Shell and tube heat exchangers, Plate heat exchangers. ***Double pipe heat exchangers*** are cheap for both design and maintenance, making them a good choice for small industries. In these exchangers one fluid flows inside the tube and the other fluid flows on the outside as shown in figure 4.1. Although they are simple and cheap, their low efficiency coupled with the high space occupied in large scales, has led modern industries to use more efficient heat exchangers like shell and tube [29].

Shell and tube heat exchangers in their various construction modifications are probably the most widespread and commonly used basic heat exchanger configuration in industry. Shell-and-tube heat exchangers are further classified according to the number of shell and tube passes involved. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C) [31].

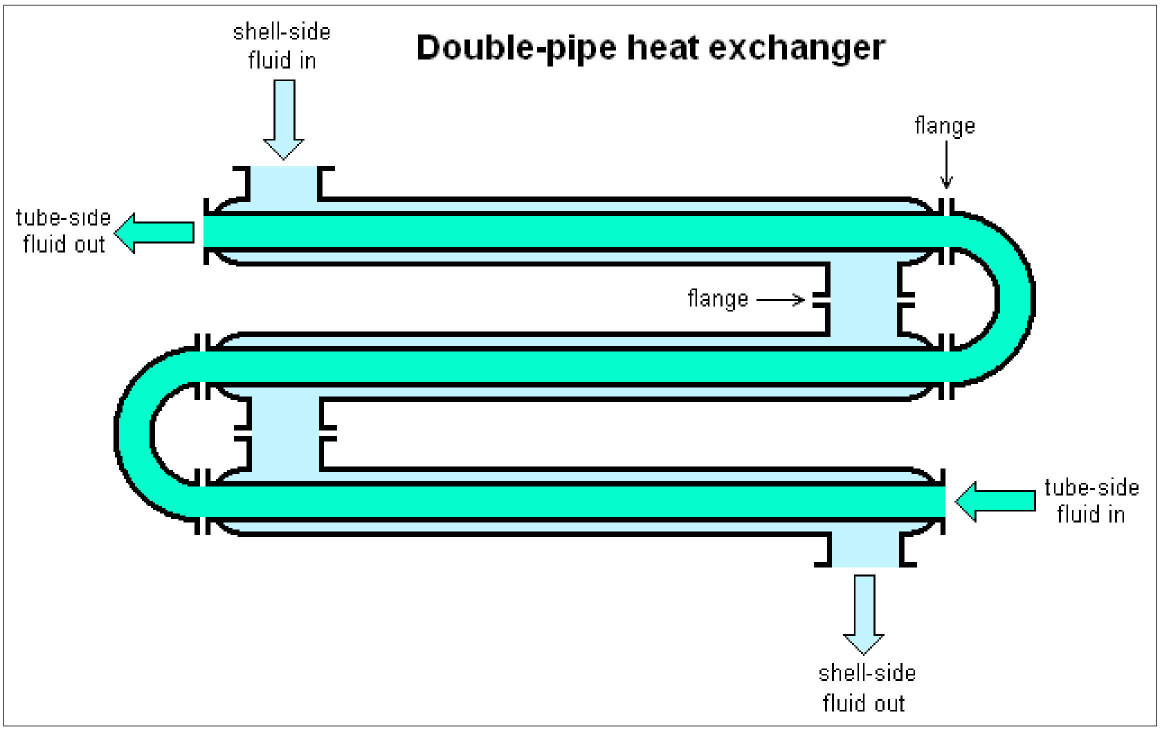


Figure 4.1: Double pipe heat exchanger.

This is because the shell and tube heat exchangers can withstand high pressures due to their shape. In this type of heat exchanger, a number of small bore pipes are fitted between two tube plates and primary fluid flows through these tubes. The tube bundle is placed inside a shell and the secondary fluid flows through the shell and over the surface of the tubes, see Figure 4.2. To increase the amount of heat transferred and the power generated, the heat exchange surface must be maximized [32, 33].

A ***plate heat exchanger*** is a type of heat exchanger that uses metal plates to transfer heat between two fluids. This arrangement is popular with heat exchangers using air or gas as well as lower velocity fluid flow. When compared to shell and tube exchangers, the stacked-plate arrangement typically has lower volume, see Figure 4.3. Another difference between the two is that plate exchangers typically serve low to medium pressure fluids, compared to medium and high pressures of shell and tube [17].

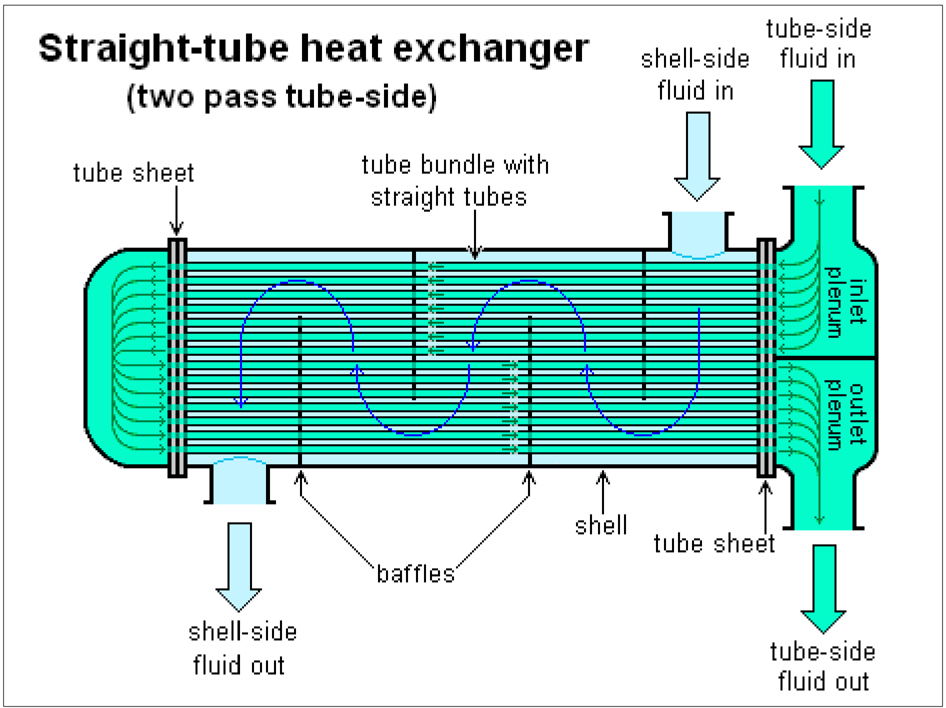


Figure 4.2: Shell and tube heat exchanger.

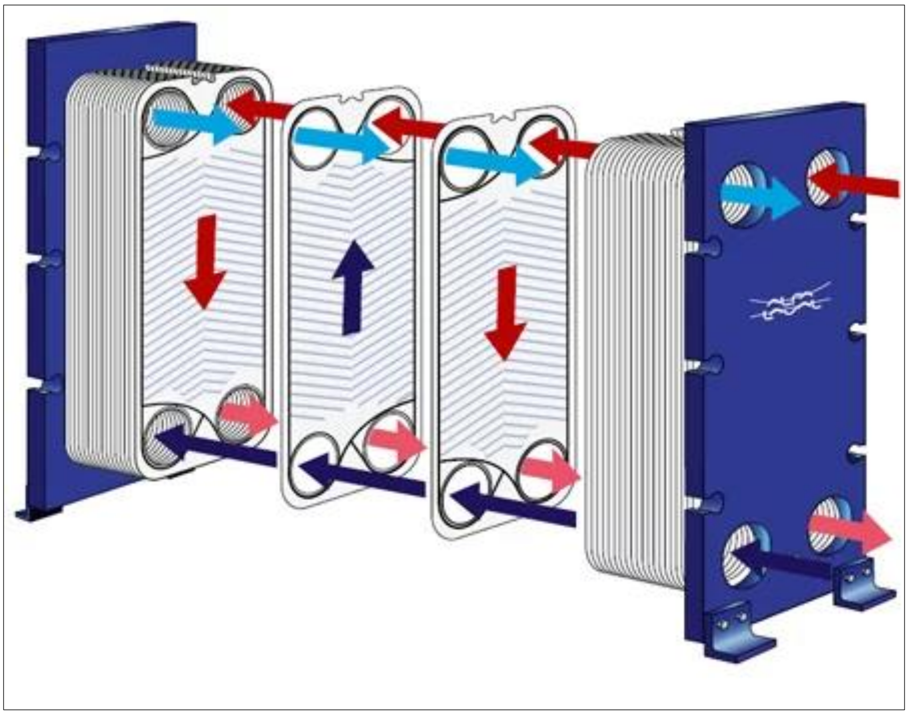


Figure 4.3: Plate heat exchanger.

In this study, plate heat exchangers will be used in the heat exchangers network, because of its higher efficiency and lower volume in comparison with other types. Although the high capital cost of plate heat exchangers, they still suitable for low and medium pressure fluids.

A software selection tool will be used in order to select the optimum heat exchangers. Alfa Laval, Danfoss and SWEP are the main manufacturers of plate heat exchangers. All mentioned manufacturers developed advanced heat exchanger selection tools. Alfa Laval and SWEP provides this service through on their websites, while Danfoss developed a downloadable software for the same purpose. The three tools lead to the same results with different equipment's. Unfortunately, Alfa Laval and SWEP have a predefined library for the working fluids, which means that the actual thermal properties of milk could not be used in calculation. Hexact V5 software by Dnfoss allows the users to define new fluids with the actual thermal properties, this option ensures more accurate results. Because of this feature, Hexact software will be used to select the required heat exchangers.

4.2 Hexact V5 Software:

Hexact enables the user to identify the right heat exchanger for heating and cooling purposes. The heat exchanger design software covers both innovative micro plate heat exchangers and traditional brazed plate heat exchangers types. The software includes three selection modes based on design, rating and performance See Figure 4.4. Initial temperature, target temperature, flow rate and thermal load of each stream are already known. Accordingly, the selection of heat exchangers will be based on performance. Flow rate and inlet temperatures of both streams are the required inputs, while outlet temperatures and load of streams are the calculated outputs by the software according to the selected heat exchanger specifications.

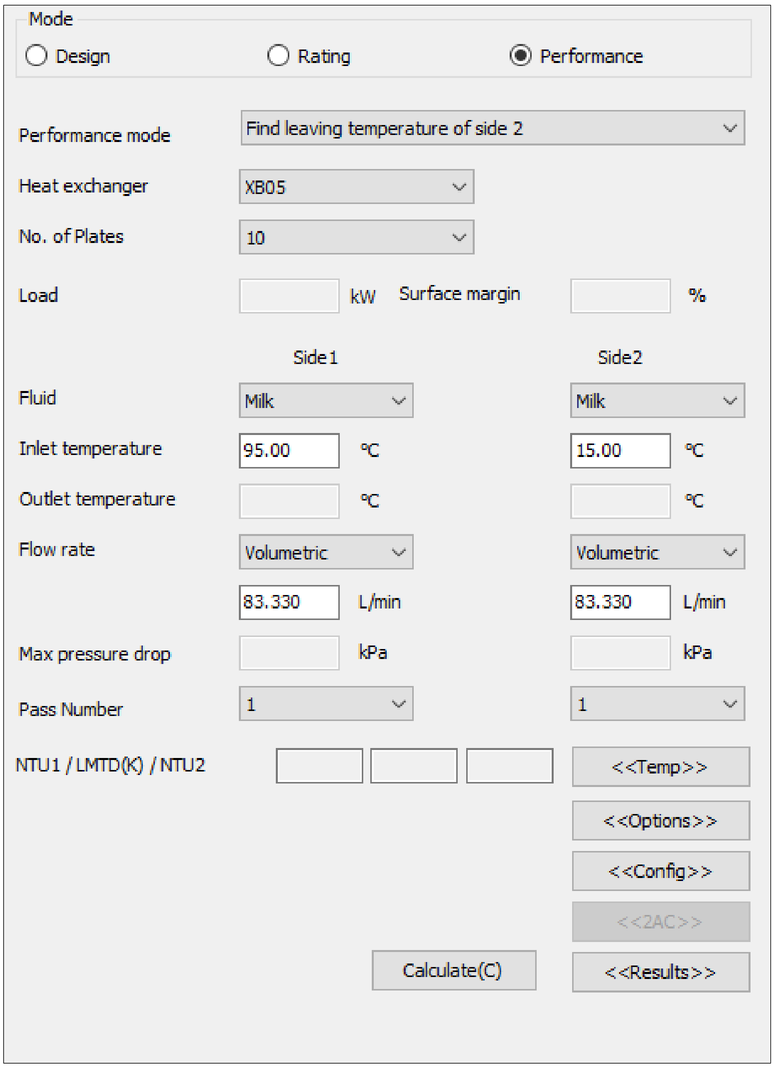


Figure 4.4: Danfoss Hexact interface.

4.3 Heat Exchangers Specifications:

Inlet temperature, outlet temperature, flow rate and load are the required parameters when selecting a heat exchanger. The selection mode will be based on the performance of the heat exchanger. The input data for the software will include the inlet temperature and the flow rate of the hot and cold streams. The software will determine the outlet temperature and calculate the load of the heat exchanger based on the selected heat exchanger. Table 4.1 includes the summary of heat exchangers specifications.

Table 4.1: Heat exchangers specifications.

Heat Exchanger	Stream	Inlet temperature [C]	Outlet temperature [C]	Flow rate [L/min]	Load [kW]
1	1	15	85	133	631
	4	95	25	133	
2	2	15	85	167	789
	5	95	25	167	
3	3	15	73	50	190
	6	95	37	50	
4	2	10	15	167	56
	5	25	20	167	

Heat exchangers 1 & 2 have very high load. The available heat exchanger (XB70H-1-140) can cover 621.74 kW only (98.5% of the required load). The price of this heat exchanger is 8245 euros, which is too high. It's better to divide the stream into two streams and to divide the load on two heat exchangers. Based on the new loads, (XB52M-2-26/26) heat exchanger can meet the new demand. The price of this heat exchanger is 1230 euros, since we need two heat exchangers, the total price is 2460 euros (almost 30% of the previous price). The same criteria will be used with heat exchanger No. 2. The specifications of selected heat exchangers are summarized in Table 4.2.

All selected heat exchangers have larger load than required due to expected losses. The actual outlet temperature of each heat exchanger is calculated by the software. Each stream will reach the target temperature as shown in Table 4.2. The price of each heat exchanger and the total prices of the heat exchangers are shown in Table 4.3

Table 4.2: Heat exchangers specifications and actual outlet temperatures.

HEX No.	Type	Stream	Inlet temp. [C]	Actual Outlet temp. [C]	Flow rate [L/min]	Load [kW]	No. of HEX's	Total Load [kW]
1	XB52M-2-26/26	1	15	85.24	66.67	316.74	2	633.48
		4	95	24.76	66.67			
2	XB52M-2	2	15	85.01	166.67	394.60	2	789.2
		5	95	24.99	166.67			
3	XG10-2	3	15	73.98	50	199.46	1	199.46
		6	95	36.02	50			
4	XG10-2-10/10	2	10	15.94	166.67	66.97	1	66.97
		5	25	19.06	166.67			

Table 4.3: Heat exchangers prices and loads.

HEX No.	Type	Code	Price [Euros]	Load [kW]	No. of HEX's	Total Load [kW]
1	XB52M-2-26/26	004H4541	1230	316.74	2	633.48
2	XB52M-2	004H4542	1304	394.60	2	789.2
3	XG10-2	004B1456	1464	199.46	1	199.46
4	XG10-2-10/10	004B1451	845	66.97	1	66.97
Total			**7377**	**-**	**6**	**1689**

The temperature profile of heat exchanger can also be obtained using the software. The cold side of HEX1 starts at 15 C and supposed to reach 85 C. It will exchange heat with the hot side, the hot side starts at 95 C and supposed to leave the HEX at 25 C. Temperature profile of heat exchanger 1 is shown in figure 4.5.

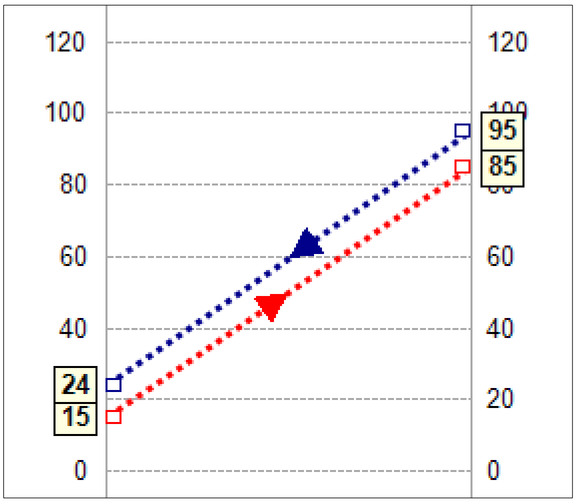


Figure 4.5: Temperature profile of heat exchanger No. 1.

The cold side of HEX2 starts at 15 C and supposed to reach 85 C. It will exchange heat with the hot side, the hot side starts at 95 C and supposed to leave the HEX at 25 C. Temperature profile of heat exchanger 2 is shown in figure 4.6.

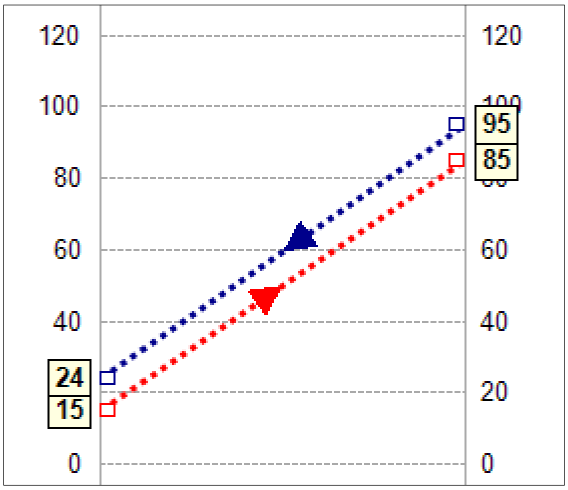


Figure 4.6: Temperature profile of heat exchanger No. 2.

The cold side of HEX3 starts at 15 C and supposed to reach 73 C. It will exchange heat with the hot side, the hot side starts at 95 C and supposed to leave the HEX at 37 C. Temperature profile of heat exchanger 3 is shown in figure 4.7.

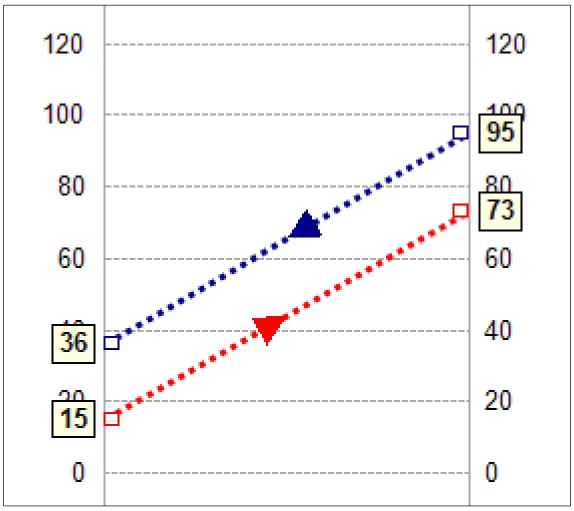


Figure 4.7: Temperature profile of heat exchanger No. 3.

The cold side of HEX4 starts at 10 C and supposed to reach 15 C. It will exchange heat with the hot side, the hot side starts at 25 C and supposed to leave the HEX at 20 C. Temperature profile of heat exchanger 5 is shown in figure 4.8.

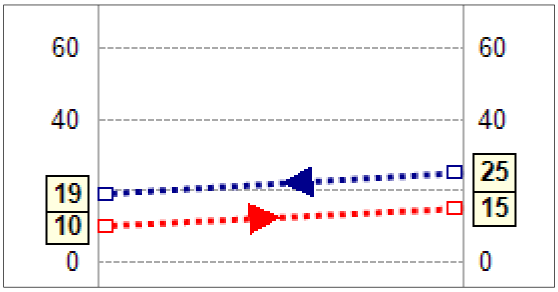


Figure 4.8: Temperature profile of heat exchanger No. 4.

All selected heat exchangers data sheets and prices are attached in the appendices. The total price of heat exchangers is 7377 euros, and the heat exchangers can cover maximum load of 1.69 MW, while the required load is 1.75 MW. The total price of heat exchangers represents the largest contributor in the capital cost of the proposed system. All economic calculations will be discussed in details in the next chapter.

Chapter 5: Economic and Environmental Evaluation

5.1 Introduction:

The approaches required to determine the economics of the proposed system will be discussed in this section. Some of this is simply applied engineering economics, but sometimes the energy systems we need to analyze, especially those involving cogeneration, require special viewpoints to adequately describe their economic advantages.

The economic viability of distributed generation systems and energy efficiency programs can be measured in many respects. The capital cost of the equipment the cost of operation and maintenance, and the cost of fuel must be balanced in some manner so that a comparison can be provided with the cost of not doing the design. Although somewhat superficial the research provided here is meant to provide a reasonable start to the financial evaluation, at least sufficient to determine if the project needs more, more careful analysis.

Al-Junaidi Company uses the diesel burners to generate hot steam, the hot steam then is used to heat milk in pasteurization process. The cold water is used to cool the hot milk after being pasteurized, cooling chillers are used to cool the cooling water. This research reduces the required external heating and cooling loads by internal heat recovery. It is important to determine the economic benefits of the designed system, the simple payback period calculations will be used in this study.

5.2 Simple Payback Period:

A simple payback calculation is one of the most popular ways to evaluate a project's economic value. This is only the proportion of the first additional cost (ΔP) to the annual savings, S:

$$Simple\ payback = \frac{Extra\ first\ cost\ (unit\ cost)}{Annual\ savings\ (unit\ cost/year)} = \frac{\Delta P}{S} \quad (7)$$

simple payback has the benefit that it is the easiest way to understand all economic measures, but it has the unfortunate problem of being one of the least most misleading measures since it doesn't include anything about the longevity of the system.

The initial (or simple) rate of return is only the opposite of the simple payback period. That is, the proportion of annual savings to additional initial investment is as follows:

$$Initial\ rate\ of\ return = \frac{Annual\ savings\ (unit\ cost/year)}{Extra\ first\ cost\ (unit\ cost)} = \frac{S}{\Delta P} \quad (8)$$

Although the initial rate of return may be misleading, it often serves a useful role as a simple "minimum threshold" measure. If the investment has an initial rate of return below the threshold, there is no need to proceed any further. Cooling and heating demand should be clearly identified before and after the application of pinch technology.

5.3 Cooling demand:

This study had analyzed three hot streams, each stream has a supply and target temperature, the flow rate and specific heat capacity are needed parameters to determine the cooling load. Table 5.1 summarize the cooling load required to cool down the hot streams, the total cooling load is 1802.442 kW.

Table 5.1: Total cooling load required.

Stream No.	Material	H/C	Supply Temp. [C]	Target Temp. [C]	ΔH [kW]
4	Milk	Hot	95	10	766.550
5	Milk	Hot	95	20	845.459
6	Fresh Milk	Hot	95	37	190.433
		Total			**1802.442**

A chiller is used to cool water that extract heat from hot milk. The chiller has coefficient of performance is 5, which mean 5 kW of cooling provided by the chiller when it consumes 1 kW electrical power. The relation between COP of the chiller and the power input and output is given through equation 6 [24]:

$$COP_{Chiller} = \frac{Refergiration\ output\ [kW]}{Electrical\ power\ input\ [kW]} \quad (9)$$

To calculate the cost of energy consumption used by the chiller, the working hours of the chiller and the price of electricity should be determined. The electricity cost for industrial use is 0.5902 NIS/kWh in Hebron [25]. The cost of electricity per day can be calculated by the following equation:

$$C_e = P \times t \times p_e \quad (10)$$

Where C_e is the total cost of electricity in NIS, P is the electrical power required in kW, t is the time in hours and p_e is the price of electrical energy in NIS/kWh. The calculations of cooling demand before and after the analysis is shown in Table 5.2.

Table 5.2: Economic calculations of cooling demand.

Total cooling demand	1.8 MW
COP of the chiller	5
Electricity cost	0.5902 NIS/kWh
Working hours per day	3 h
Electrical power required per day	360 kW
Cost per day before analysis	638 NIS
Cooling demand after analysis	1746 kW
Cost per day after analysis	618 NIS
Daily Savings	20 NIS

As shown in Table 5.2, the running cost of the cooling chiller for the analyzed pasteurizers is 628 NIS per day. After the application of pinch analysis, the cost dropped down to be 618 NIS per day. The initial estimations indicates 3% possible saving on the cost of cooling process, the previous calculations does not take in consideration the capital cost of the system.

5.4 Heating demand:

Three cold streams were analyzed in this study, each stream has a supply and target temperature, the flow rate and specific heat capacity are needed parameters to determine the cooling load. Table 5.3 summarize the heating load required to heat up the cold streams, the total heating load is 2032.494 kW.

Table 5.3: Total heating load required:

Stream No.	Material	H/C	Supply Temp. [C]	Target Temp. [C]	ΔH [kW]
1	Milk	Cold	5	95	811.641
2	Milk	Cold	10	95	958.187
3	Fresh Milk	Cold	15	95	262.667
		Total			**2032.494**

A diesel burner is used to generate steam needed to heat the cold milk. The boiler has an efficiency of 95%. To calculate the cost of energy consumption used by the boiler, the working hours of the boiler, the amount of diesel required and the price of diesel should be determined. The density of diesel is about 0.832 kg/L [26], and the calorific value is 45.6 MJ/kg [27]. The total heating demand required is 2032.494 kW, since the boiler efficiency is 95% the required heating load by the diesel itself will be 2139.47 kW. The mass (in kg) of diesel required can be calculated by the following equation:

$$M_{diesel} = \frac{P_r \times t \times 3600}{1000 \times HV} \quad (11)$$

Where P_r is the required power in kW, t is the time in hours and HV is the heating value in MJ/kg. According to the previous equation, 506.71 kg (or 609.03 L) of diesel are needed to meet the heating load required before applying pinch analysis. If the price of diesel is 4.99 NIS/L, then the total cost of diesel 3039.08 NIS per day. After the application of pinch analysis, the heating load required is 696.83 kW, and the cost will be 1649.73 NIS per day. The calculations of heating demand before and after the analysis is shown in Table 5.4.

Table 5.4: Economic calculations of heating demand.

Total heating demand	2032.494 kW
Boiler efficiency	95%
Diesel cost	5 NIS/L
Diesel density	0.832 kg/L
Diesel heat content	45.6 MJ/kg
Load required by diesel	2139.467793 kW
Mass of diesel required	513 kg
Volume of diesel required	617 L
Working hours per day	3 h
Cost per day before analysis	3085 NIS
Heating demand after analysis	696.83 kW
Cost per day after analysis	1675 NIS
Daily Savings	1410 NIS

As shown in Table 5.4, the running cost of the boiler for the analyzed pasteurizers is 3085 NIS per day. After the application of pinch analysis, the cost dropped down to be 1675 NIS per day. The initial estimations indicates 45% possible saving on the cost of heating process, the previous calculations does not take in consideration the capital cost of the system.

5.5 Economic Calculations:

After determining the cost per day for cooling and heating demand, the capital cost should be determined. The total price of is 29500 NIS (7377 Euros), which is the main contributor to the capital cost. Delivery, installation and accessories costs are the other contributors to the capital cost of the system. According to the manufacturer terms of delivery, the cost of delivery is 20% of the total cost of equipment. Cost of accessories required for the system is estimated to be 15000 NIS, while the cost of installation is assumed to be 10000 NIS. The summary of capital cost of the system is shown in Table 5.5.

Table 5.5: Capital costs.

Item	Cost [NIS]
Heat exchangers price	29500
Accessories	15000
Cost of delivery	5900
Cost of installation	10000
Total Capital Cost	**60400**

The annual savings per years can be calculated based on the energy cost per day and annual costs of the system. The actual working days per year are estimated to be 300 days due to vacations. The calculated system daily savings are 1430 NIS per day, which means 429000 NIS per year. The maintenance cost is supposed to be 10% of the annual savings. Since the 5 years warranty on heat exchangers by the company, the depreciation cost of the equipment is considered 20% per year. Table 5.6 summarize the annual costs.

Table 5.6: Annual costs.

Item	Cost [NIS]
Daily savings	1430 NIS
Annual savings	429000 NIS/year
Maintenance	42900 NIS/year
Depreciation	12080 NIS/year
Net Annual Savings	**374195 NIS/year**

The calculations indicates huge saving's potential,

$$Simple\ payback = \frac{60400}{374195} = 2\ months$$

The calculated load for each heat exchanger is a good indicator of the heat echanger benefit. But it does not make sense to take the benefit in consideration without comparing the benefit with the cost of the heat exchanger. Benefit Cost Approach (BCA) can be a valuable aid to evaluate the feasibility of each heat exchanger individually. Table 5.7 includes the benefit, cost and B/C ratio of each heat exchanger.

Table 5.7: Benefit/Cost Analysis for HEXs network

HEX No.	1	2	3	4
Type	XB52M-2-26/26	XB52M-2	XG10-2	XG10-2-20/20
Load [kW]	316.7	2×394.6	199.5	95.4
No. of HEX's	2	2	1	1
Price [Euros]	1230	1304	1464	1063
Price [NIS]	5227.5	5542	6222	4517.8
Benefit/ day	432.8	539.2	272.5	130.3
Benefit/year	129837.8	161754	81762.4	39098.1
Total Cost	22637	23517.6	12710.8	10324.9
Benefit/Cost	5.7	6.9	6.4	3.8

The final design obtained with the modification is presented in Figure 5.1. In this configuration four new heat echangers are added to the network. The details of each heat exchangers with economic indicators are explained in this sketch. It can be seen that all modifications had an positive impact on the energy consumption.

5.6 Carbon Dioxide Emissions:

Increasing sustainability by energy efficiency in industrial processing is an issue of considerable interest. The need to reduce energy consumption and CO_2 emissions in all sectors of society are pushing the need for research and implementation on efficient energy methods. Wherefore, the CO_2 of emissions of the targeted pasteurizers can be calculated based on the heating load required by the diesel boiler. The CO_2 emissions before and after the pinch analysis can be compared.

Each liter of diesel weighs 832 grams [26]. The average chemical formula of diesel fuel is $C_{12}H_{24}$. The molar mass of diesel fuel is 168 g/mole, and the carbon content is about 85.7%. or 713.14 grams of carbon per liter of diesel. In order to combust this carbon to CO_2, 1902.4 grams of oxygen are needed. The sum is then 713.14 + 1902.4 = 2615.8 grams of CO_2/liter diesel.

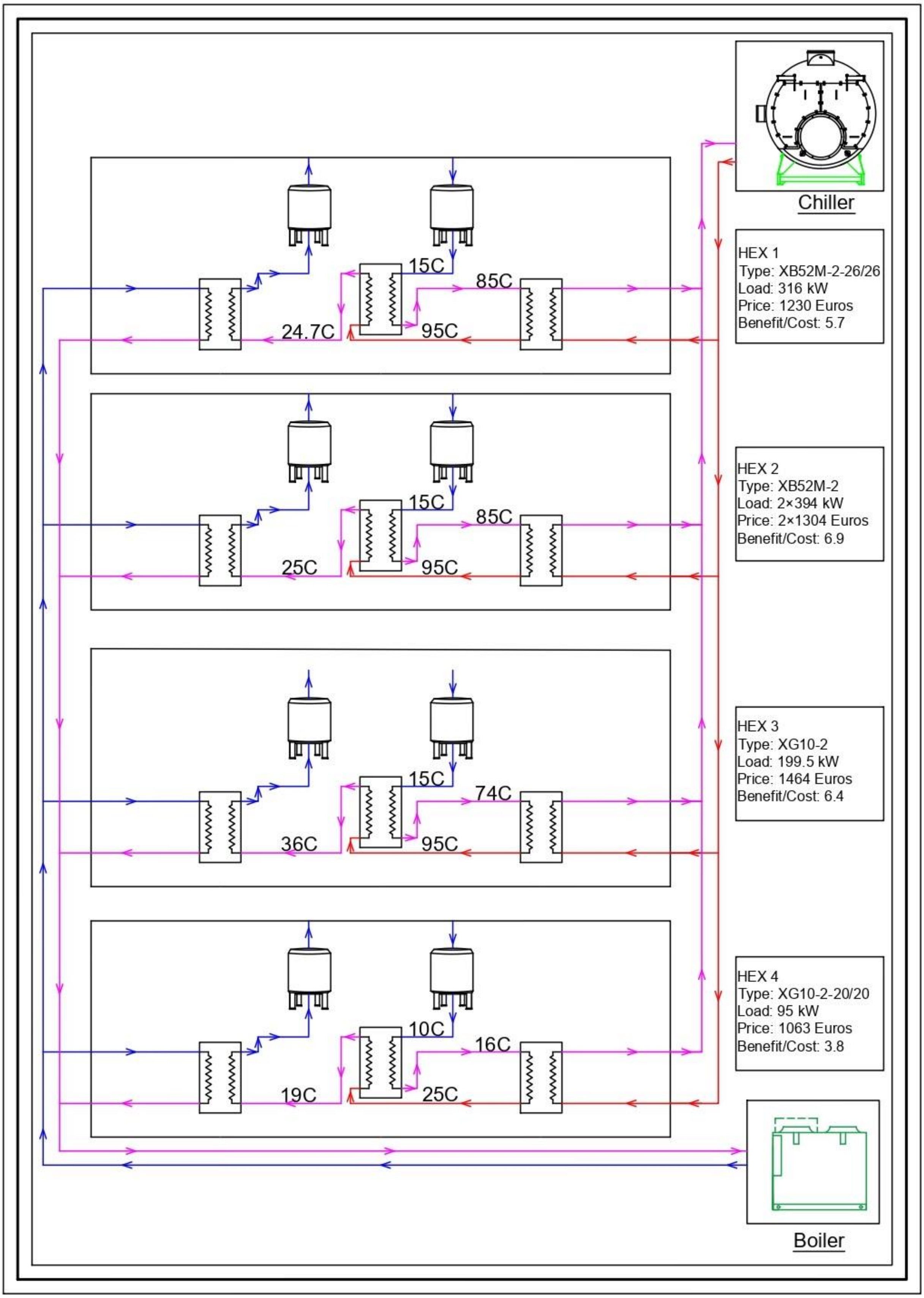


Figure 5.1: Detailed heat exchangers network.

The amount of diesel required per day was 617 L, and the boiler is expected to work 300 days per year. The total CO_2 emissions by the analyzed pasteurizers is 484 tons CO_2/year. After the heat integration, the amount of diesel required per day dropped down to 335 L. The annual CO_2 emissions by the targeted utilities is around 263 tons CO_2/year. The new diesel consumption is 54.3% of the previous one, which means 45.7% reduction in CO_2 emissions by the targeted utilities is possible through the application of pinch technology.

Chapter 6: Conclusions and Future Work

6.1 Conclusions:

The study has shown that the pasteurization process at Al-Junaidi Company for Food and Dairy Products has theoretical maximum recoverable energy of 1.7 MW, theoretical minimum external heating load requirement of 275 kW and a theoretical minimum cooling load of 45 kW. These values can be put in comparison with the current utilities demand of 2 MW and 1.8 MW for heating load and cooling load requirements respectively. This means that 90% of the cooling and heating demand could be saved if a design meeting these targets was to be implemented with the minimum demands in consideration. The investment decisions that peg on the simple payback period may not favor the full implementation of the decision. However, some parts of the design can be implemented, leading to considerable savings.

The design has 6 heat exchangers, 3 external heating loads and 1 external cooling load. Implementation of the energy recovery network design was found to cost 60400 NIS and would enable the company to make savings of 429000 NIS per year. The project will have a simple payback period of two months. The retrofit design can be implemented in part or wholly. The plant survey for the research was for two weeks.

The diesel consumption decreased from 617 L per day to 335 L per day. The reduction of diesel consumption lead to reduction in CO_2 emissions. The estimated CO_2 emissions before integration was 478 tons CO_2/year, while the analysis estimated the CO_2 emissions to be 260 tons CO_2/year after the implimntation of the proposed heat exchangers network. This means that 45% of CO_2 emissions would be saved if the design meets its targets.

6.2 Future Work:

One major challenge encountered during the course of this study was to obtain reliable cost and performance data from Al-Junaidi Company. This constraint can be overcome by developing an experimental set of equipment in order to verify some of the data obtained from the published literature. Therefore, the author suggests that further research should be carried out to develop a total site analysis using pinch technology. The total site analysis can be used to estimate energy targets for the entire site, and to identify key process changes that will lower the entire site energy consumption. In addition, water pinch technique can be used to analyze water networks and minimize water costs for processes. The best water reuse, regeneration and treatment opportunities can be optimized.

References:

[1] International Energy Agency (2017). https://www.iea.org/

[2] Khan, F., 2008. Waste Heat Recovery. Process Systems Engineering Department, Cranfield University, United Kingdom.

[3] Ozalp, N. and Hyman, B., 2007. Allocation of energy inputs among the end-uses in the US petroleum and coal products industry. Energy, 32(8), pp.1460-1470.

[4] Bakhtiari, B. and Bedard, S., 2013. Retrofitting heat exchanger networks using a modified network pinch approach. Applied Thermal Engineering, 51(1-2), pp.973-979.

[5] Fenwicks, M., Kinyua, R. and Aganda, A., 2014. Energy Efficiency Analysis Using Pinch Technology: A Case Study of Orbit Chemicals Industry. Journal of Mechanical and Civil Engineering, 11(3), pp.44-53.

[6] Prajapat, R., 2014. Pasteurization process energy optimization for a milk dairy plant by energy audit approach. International Journal of Scientific & Technology Research, 3(6), pp.181-188.

[7] El-Temtamy, S.A., Hamid, I., Gabr, E.M. and Sayed, A.E.R., 2010. The Use of Pinch Technology to Reduce Utility Consumption in a Natural Gas Processing Plant. Petroleum Science and Technology, 28(13), pp.1316-1330.

[8] Gadalla, M.A., 2015. A new graphical method for Pinch Analysis applications: Heat exchanger network retrofit and energy integration. Energy, 81, pp.159-174.

[9] Walmsley, T.G., Atkins, M.J., Walmsley, M.R. and Neale, J.R., 2016. Appropriate placement of vapour recompression in ultra-low energy industrial milk evaporation systems using Pinch Analysis. Energy, 116, pp.1269-1281.

[10] Gadalla, M.A., 2015. A new graphical method for Pinch Analysis applications: Heat exchanger network retrofit and energy integration. Energy, 81, pp.159-174.

[11] Umar, B.N., Ahmed, E.N.U. and Ahmed, S.I., 2017. Energy Integration of Sugar Production Plant Using Pinch Analysis: A Case Study of Savanah Sugar Company Yola, Nigeria. Pelagia Research Library, 8, pp. 20-29.

[12] Misevičiūtė, V., Motuzienė, V. and Valančius, K., 2018. The application of the Pinch method for the analysis of the heat exchangers network in a ventilation system of a building. Applied Thermal Engineering, 129, pp.772-781.

[13] Li, B.H., Castillo, Y.E.C. and Chang, C.T., 2019. An improved design method for retrofitting industrial heat exchanger networks based on Pinch Analysis. Chemical Engineering Research and Design.

[14] Linnhoff, B., 1972. Thermodynamic analysis of the cement burning process (Thermodynamische Analyse des Zementbrennprozesses) (Diploma Work). Abteilung IIIa, ETH Zurich.

[15] Linnhoff, B., 1982. User guide on process integration for the efficient use of energy. AIChE J., 28, pp.152-236.

[16] March, L., 1998. Introduction to pinch technology. Targeting House, Gadbrook Park, Northwich, Cheshire, CW9 7UZ, England.

[17] Kemp, I.C., 2011. Pinch analysis and process integration: a user guide on process integration for the efficient use of energy. Elsevier.

[18] Johansson, D. and Harvey, S., 2009. An Analysis for identifying Energy Saving Opportunities for a Petrochemical Cluster in Times of Climate Change. Chemical Engineering Transactions, 18, pp.469-474.

[19] Prajapat, R., 2014. Pasteurization process energy optimization for a milk dairy plant by energy audit approach. International Journal of Scientific & Technology Research, 3(6), pp.181-188.

[20] B. Gosta"Dairy processing handbook" Tetra Pak
Processing Systems ABS-221 86 Lund (1995), Sweden.

[21] Types of Pasteurization for Dairy Products. [online] Available at: https://www.deliciousobsessions.com/2010/10/types-pasteurization/ [Accessed 22 Dec. 2019].

[22] Kemp, I.C., 2007. Pinch analysis and process integration: a user guide on process integration for the efficient use of energy. Elsevier.

[23] M. Gandiglio, A. Lanzini, M. Santarelli, P. Leone, Design and optimization of a proton exchange membrane fuel cell CHP system for residential use, Energy & Buildings. 69 (2014) 381–393. doi:10.1016/j.enbuild.2013.11.022.

[24] Wang, S.K. and Wang, S.K., 2000. Handbook of air conditioning and refrigeration (Vol. 49). New York: McGraw-Hill.

[25] Hepco-pal.com. (2019). كهرباء الخليل :: en. [online] Available at: http://hepco-pal.com/en [Accessed 22 Dec. 2019].

[26] Karaeen, M., El-Khateeb, I., Jaradat, A., Samara, M. and Bannoura, M., 2013. Fuel quality implications on combustion engines in the West Bank area of Palestine.

[27] IOR Petroleum. (2019). Diesel Fleet Card For Business | Wholesale Diesel Fuel Prices | IOR. [online] Available at: https://www.ior.com.au/fuel-solutions/diesel-stops/ [Accessed 22 Dec. 2019].

[28] Incropera, F.P., Lavine, A.S., Bergman, T.L. and DeWitt, D.P., 2007. Fundamentals of heat and mass transfer. Wiley.

[29] Plant, N.P., Island, N., Island, T., Pool, S.F., Pump, R.C., Turbines, S., Turbine, I., Turbine, R., Turbine, C., Turbine, B.P. and Turbine, R., 1992. Introduction to heat transfer.

[30] U.S. Department of Energy, 2016. Thermodynamics, Heat Transfer and Fluid Flow. DOE Fundamentals Handbook (Vol 2 of 3). Washington, D.C. 20585.

[31] Cengel, Y.A., 2007. Heat Transfer: A Practical Approach.

[32] Klemes, J., Smith, R. and Kim, J.K. eds., 2008. Handbook of water and energy management in food processing. Elsevier.

[33] Klemes, J.J. ed., 2013. Handbook of process integration (PI): minimisation of energy and water use, waste and emissions. Elsevier.

APPENDICES

Appendix A: Heat Exchangers Datasheets

Appendix B: Boiler Datasheet

Appendix C: Chiller Datasheet

Appendix A: Heat Exchangers Datasheets

Plate Heat Exchanger Datasheet

Danfoss Hexact(v5.2.25) **Ref.:** ZT20191214131642

Customer:		*Contact person:*	
Project:		*E-mail:*	
HEX Type:	XB52M-2-26/26	*Engineer:*	ZT
Unit:	1 (Parallel) Code: 004H4541	*Date:*	12/14/2019 1:16:47 PM

Calculated parameters	**Unit**	**Side1**	**Side2**
Flow Type		Counter current	
Load	kW	316.74	
Inlet temperature	°C	15.00	95.00
Outlet temperature (Specified)	°C	--	--
Outlet temperature (Actual)	°C	85.24	24.76
Mass Flowrate	kg/h	4120.0	4120.0
Volumetric Flowrate	L/min	66.667	66.667
Total pressure drop	kPa	18.93	17.10
Pressure drop - In port	kPa	0.18	0.18
Fouling factor	m^2-K/kW	0.000001	0.000001
Total area	m^2	5.25	
Surface margin	%	0.0	
LMTD	K	9.76	
HTC(Available / Service / Required)	W/m^2-K	6184.2/6184.2/6184.1	
Port velocity	m/s	0.52	0.52

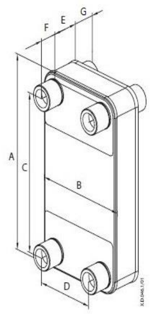
Properties of fluid	**Unit**	**Side1**	**Side2**
Fluid		Milk	Milk
Dynamic viscosity	mPa-s	0.5484	0.4968
Density	kg/m^3	1030.0	1030.0
Heat capacity	kJ/kg-K	3.940	3.940
Thermal conductivity	W/m-K	0.639	0.647

Specification:	**Unit**	**Side1**	**Side2**
HEX Type:		XB52M-2-26/26	
Number of plates:	---	52	
Max.number of plates in current frame:	---	--	
Grouping:	---	(1*12M+1*13M)/(1*13M+1*13M)	
Plate Material:	---	EN1.4404(AISI316L)	
Gasket / Brazing Material:	---	CU	
Connection size:	---	G 2	
Connection type:	---	Thread	
Frame color:	---	--	
Certification/Approval type:	---	PED Art 4.3	
Volume:	L	3.95	4.108
Weight:	kg	22.15	
Design Temp. (Max/Min):	°C	95/15	
Design Pressure(Max):	bar	25	

Items:		
Code	Pcs	Components
004H4541	1	XB52M-2-26/26

External Dimensions:			
A (mm):	466	B (mm):	256
C (mm):	379	D (mm):	170
E (mm):	108.6	F (mm):	50
G (mm):	42		

Warning: Dimensions are for reference purposes only and are not to be used for construction.



Comments:

Copper brazed stainless steel heat exchanger designed and configured for district heating systems, district cooling and other heating applications. The brazed heat exchanger features our new MICRO PLATES™, which enable heat to be transferred more effectively than in any previous model.Energy and cost savings, Longer life time, Corrosion-resistant design, Compact Design.

Plate Heat Exchanger Datasheet

Danfoss Hexact(v5.2.25) **Ref.:** ZT20191214131906

Customer:		*Contact person:*	
Project:		*E-mail:*	
HEX Type:	XB52M-2	*Engineer:*	ZT
Unit:	1 (Parallel) Code: 004H4542	*Date:*	12/14/2019 1:19:13 PM

Calculated parameters	**Unit**	**Side1**	**Side2**
Flow Type		Counter current	
Load	kW	394.60	
Inlet temperature	°C	15.00	95.00
Outlet temperature (Specified)	°C	--	--
Outlet temperature (Actual)	°C	85.01	24.99
Mass Flowrate	kg/h	5150.0	5150.0
Volumetric Flowrate	L/min	83.333	83.333
Total pressure drop	kPa	21.80	19.89
Pressure drop - In port	kPa	0.28	0.28
Fouling factor	m^2-K/kW	0.000005	0.000005
LMTD	K	9.99	
Port velocity	m/s	0.65	0.65

Properties of fluid	**Unit**	**Side1**	**Side2**
Fluid		Milk	Milk
Dynamic viscosity	mPa-s	0.5490	0.4962
Density	kg/m^3	1030.0	1030.0
Heat capacity	kJ/kg-K	3.940	3.940
Thermal conductivity	W/m-K	0.639	0.647

Specification:	**Unit**	**Side1**	**Side2**
HEX Type:		XB52M-2	
Plate Material:	---	EN1.4404(AISI316L)	
Gasket / Brazing Material:	---	CU	
Connection size:	---	G 2	
Connection type:	---	Thread	
Frame color:	---	--	
Certification/Approval type:	---	PED Art 4.3	
Volume:	L	4.582	4.74
Weight:	kg	24.31	
Design Temp. (Max/Min):	°C	95/15	
Design Pressure(Max):	bar	25	

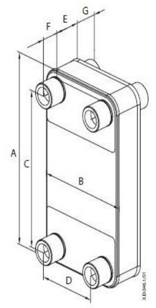
Items:

Code	Pcs	Components
004H4542	1	XB52M-2

External Dimensions:

A (mm):	466	B (mm):	256
C (mm):	379	D (mm):	170
E (mm):	122.6	F (mm):	50
G (mm):	42		

Warning: Dimensions are for reference purposes only and are not to be used for construction.



Comments:

Copper brazed stainless steel heat exchanger designed and configured for district heating systems, district cooling and other heating applications. The brazed heat exchanger features our new MICRO PLATES™, which enable heat to be transferred more effectively than in any previous model.Energy and cost savings, Longer life time, Corrosion-resistant design, Compact Design.

Plate Heat Exchanger Datasheet

Danfoss Hexact(v5.2.25) **Ref.:** ZT20191214130504

Customer:		*Contact person:*	
Project:		*E-mail:*	
HEX Type: XG10-2		*Engineer:*	ZT
Unit: 1 (Parallel)	Code: 004B1456	*Date:*	12/14/2019 1:05:16 PM

Calculated parameters	**Unit**	**Side1**	**Side2**
Flow Type		Counter current	
Load	kW	199.46	
Inlet temperature	°C	15.00	95.00
Outlet temperature (Specified)	°C	--	--
Outlet temperature (Actual)	°C	73.98	36.02
Mass Flowrate	kg/h	3090.0	3090.0
Volumetric Flowrate	L/min	50.000	50.000
Total pressure drop	kPa	31.25	28.26
Pressure drop - In port	kPa	0.72	0.72
Fouling factor	m^2-K/kW	0.000002	0.000002
LMTD	K	21.02	
Port velocity	m/s	1.10	1.10

Properties of fluid	**Unit**	**Side1**	**Side2**
Fluid		Milk	Milk
Dynamic viscosity	mPa-s	0.6859	0.4670
Density	kg/m^3	1030.0	1030.0
Heat capacity	kJ/kg-K	3.940	3.940
Thermal conductivity	W/m-K	0.630	0.652

Specification:	**Unit**	**Side1**	**Side2**
HEX Type:		XG10-2	
Plate Thickness:	mm	0.5	
Plate Material:	---	EN1.4404(AISI316L)	
Gasket / Brazing Material:	---	EPDM	
Connection size:	---	G 1	
Connection type:	---	Thread	
Frame color:	---		
Certification/Approval type:	---	PED Art 4.3	
Volume:	L	1.575	1.62
Weight:	kg	26.08	
Design Temp. (Max/Min):	°C	95/15	
Design Pressure(Max):	bar	16	

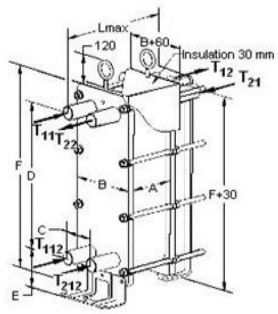
Items:

Code	Pcs	Components
004B1456	1	XG10-2

External Dimensions:

A (mm):	187.2	B (mm):	158
C (mm):	65	D (mm):	235
E (mm):	188.0	F (mm):	460
Lmax (mm):	500		

Warning: Dimensions are for reference purposes only and are not to be used for construction.



Comments:

The gasketed heat exchangers are made of shape-pressed heat plates between which the flow channels are created. Gaskets between the plates separate the flow channels from each other so that the flows do not mix. The plate heat exchanger has been developed specifically for District Energy applications like District Heating and Cooling ensuring you a reliable high efficient plate heat exchanger.Improved plate alignment system, Glue free gaskets with a robust attachment system, Enforced distribution area: Stronger plate and increased lifetime, Optimized distribution area ensures high efficiency and reduced risk of fouling, Reinforced Diagonal Groove: Longer run time.

Plate Heat Exchanger Datasheet

Danfoss Hexact(v5.2.25) **Ref.:** ZT20191214145619

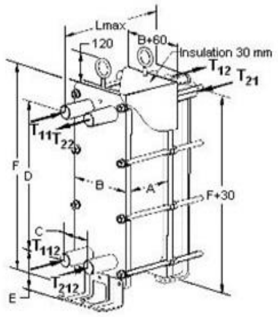
Customer:				*Contact person:*	
Project:				*E-mail:*	
HEX Type:		XG10-2-10/10		*Engineer:*	ZT
Unit:	1 (Parallel)	Code:	004B1451	*Date:*	12/14/2019 2:56:25 PM

Calculated parameters	**Unit**	**Side1**		**Side2**
Flow Type			Counter current	
Load	kW		75.51	
Inlet temperature	°C	5.00		25.00
Outlet temperature (Specified)	°C	--		--
Outlet temperature (Actual)	°C	13.37		16.63
Mass Flowrate	kg/h	8240.0		8240.0
Volumetric Flowrate	L/min	133.333		133.333
Total pressure drop	kPa	2886.41		2241.42
Pressure drop - In port	kPa	5.13		5.13
Fouling factor	m^2-K/kW	-0.000002		-0.000002
Total area	m^2		0.49	
Surface margin	%		0.0	
LMTD	K		11.63	
HTC(Available / Service / Required)	W/m^2-K		13361.6/13361.6/13362.2	
Port velocity	m/s	2.94		2.94

Properties of fluid	**Unit**	**Side1**	**Side2**
Fluid		Milk	Milk
Dynamic viscosity	mPa-s	1.5624	1.2737
Density	kg/m^3	1030.0	1030.0
Heat capacity	kJ/kg-K	3.940	3.940
Thermal conductivity	W/m-K	0.569	0.589

Specification:	**Unit**	**Side1**		**Side2**
HEX Type:			XG10-2-10/10	
Number of plates:	---		20	
Max.number of plates in current frame:	---		31	
Grouping:	---		(1*4+1*5)/(1*5+1*5)	
Plate Thickness:	mm		0.5	
Plate Material:	---		EN1.4404(AISI316L)	
Gasket / Brazing Material:	---		EPDM	
Connection size:	---		G 1	
Connection type:	---		Thread	
Frame color:	---			
Certification/Approval type:	---		PED Art 4.3	
Volume:	L	0.405		0.45
Weight:	kg		18.8	
Design Temp. (Max/Min):	°C		25/5	
Design Pressure(Max):	bar		16	

Items:		
Code	Pcs	Components
004B1451	1	XG10-2-10/10



External Dimensions:			
A (mm):	52	B (mm):	158
C (mm):	65	D (mm):	235
E (mm):	188.0	F (mm):	460
Lmax (mm):	500		

Warning: Dimensions are for reference purposes only and are not to be used for construction.

Comments:

The gasketed heat exchangers are made of shape-pressed heat plates between which the flow channels are created. Gaskets between the plates separate the flow channels from each other so that the flows do not mix. The plate heat exchanger has been developed specifically for District Energy applications like District Heating and Cooling ensuring you a reliable high efficient plate heat exchanger.Improved plate alignment system, Glue free gaskets with a robust attachment system, Enforced distribution area: Stronger plate and increased lifetime, Optimized distribution area ensures high efficiency and reduced risk of fouling, Reinforced Diagonal Groove: Longer run time.

Plate Heat Exchanger Datasheet

Danfoss Hexact(v5.2.25) **Ref.:** ZT20191214140502

Customer:		*Contact person:*	
Project:		*E-mail:*	
HEX Type:	XG10-2-10/10	*Engineer:*	ZT
Unit:	1 (Parallel) Code: 004B1451	*Date:*	12/14/2019 2:05:10 PM

Calculated parameters	**Unit**	**Side1**	**Side2**
Flow Type		Counter current	
Load	kW	66.97	
Inlet temperature	°C	10.00	25.00
Outlet temperature (Specified)	°C	--	--
Outlet temperature (Actual)	°C	15.94	19.06
Mass Flowrate	kg/h	10300.0	10300.0
Volumetric Flowrate	L/min	166.667	166.667
Total pressure drop	kPa	4398.04	3426.47
Pressure drop - In port	kPa	8.02	8.02
Fouling factor	m^2-K/kW	0.000002	0.000002
Total area	m^2	0.49	
Surface margin	%	0.0	
LMTD	K	9.06	
HTC(Available / Service / Required)	W/m^2-K	15211.8/15211.8/15211.0	
Port velocity	m/s	3.68	3.68

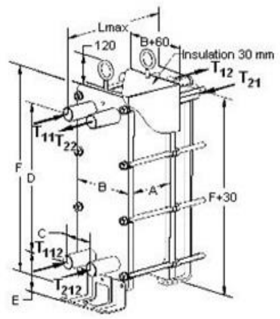
Properties of fluid	**Unit**	**Side1**	**Side2**
Fluid		Milk	Milk
Dynamic viscosity	mPa-s	1.4685	1.2435
Density	kg/m^3	1030.0	1030.0
Heat capacity	kJ/kg-K	3.940	3.940
Thermal conductivity	W/m-K	0.576	0.591

Specification:	**Unit**	**Side1**	**Side2**
HEX Type:		XG10-2-10/10	
Number of plates:	---	20	
Max.number of plates in current frame:	---	31	
Grouping:	---	(1*4+1*5)/(1*5+1*5)	
Plate Thickness:	mm	0.5	
Plate Material:	---	EN1.4404(AISI316L)	
Gasket / Brazing Material:	---	EPDM	
Connection size:	---	G 1	
Connection type:	---	Thread	
Frame color:	---		
Certification/Approval type:	---	PED Art 4.3	
Volume:	L	0.405	0.45
Weight:	kg	18.8	
Design Temp. (Max/Min):	°C	25/10	
Design Pressure(Max):	bar	16	

Items:		
Code	Pcs	Components
004B1451	1	XG10-2-10/10

External Dimensions:			
A (mm):	52	B (mm):	158
C (mm):	65	D (mm):	235
E (mm):	188.0	F (mm):	460
Lmax (mm):	500		

Warning: Dimensions are for reference purposes only and are not to be used for construction.



Comments:

The gasketed heat exchangers are made of shape-pressed heat plates between which the flow channels are created. Gaskets between the plates separate the flow channels from each other so that the flows do not mix. The plate heat exchanger has been developed specifically for District Energy applications like District Heating and Cooling ensuring you a reliable high efficient plate heat exchanger.Improved plate alignment system, Glue free gaskets with a robust attachment system, Enforced distribution area: Stronger plate and increased lifetime, Optimized distribution area ensures high efficiency and reduced risk of fouling, Reinforced Diagonal Groove: Longer run time.

Appendix B: Boiler Datasheet

The Heating Engineer

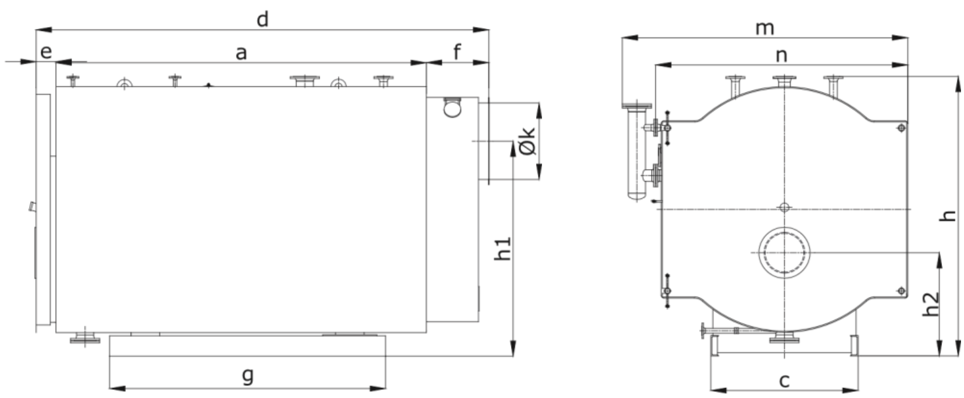
SP

* 0,25-5,5 t/h steam generation capacity
* 6-16 bar operating pressure
* Liquid and gas fueled
* Can be used with pressure jet burner
* Up-to 91% boiler efficiency. Up-to 95.5% efficiency in econ
applications.
* Easy assembly and interference with platform on the boiler
* Standard equipment: Steam outlet, feed water intake, airven
discharge, surface blow off valves and safety valves, feed wa
group, operation and safety accessories, electric control panel
* Optional water, air economizer use

Fluid and Gas Fueled, Two-Pass, High Pressure Steam Boiler

SP

Fluid and Gas Fueled, Two-Pass, High Pressure Steam Boiler



Technical Specifical	Unit	25	32	40	50	65	80	100	125	160	200	250	300	400
Capacity	kg/h	250	320	400	500	650	800	1.000	1.250	1.600	2.000	2.500	3.000	4.000

Capacity	kW	164	209	262	327	426	524	655	818	1.047	1.309	1.637	1.964	2.619
Fuel Amount (Natural Gas)	[Nm^3/h]	19	24	30	38	49	61	76	95	121	152	190	227	303
Fuel Amount (Fuel-Oil)	kg/h	17	22	27	34	44	54	67	84	108	134	168	202	269
Water Volume	lt	510	510	750	750	930	930	1.150	1.530	1.860	2.170	3.100	3.460	4.380
Steam Volume	lt	175	175	220	220	249	249	286	329	383	604	1.003	1.388	1.611
a	mm	1.325	1.325	1.645	1.645	1.785	1.785	1.985	2.185	2.395	2.655	2.850	3.200	3.425
Øb	mm	1.192	1.192	1.262	1.262	1.342	1.342	1.422	1.500	1.572	1.672	1.944	2.022	2.132
c	mm	700	700	740	740	800	800	850	900	960	1.040	1.170	1.190	1.365
d	mm	1.863	1.863	2.183	2.183	2.388	2.388	2.573	2.788	2.983	3.350	3.490	3.840	4.115
e	mm	228	228	228	228	228	228	228	228	228	270	180	180	180
f	mm	310	310	310	310	360	360	360	360	360	410	460	460	510
g	mm	940	940	1.180	1.180	1.314	1.314	1.480	1.780	1.780	2.100	2.000	2.500	2.650
h	mm	1.556	1.556	1.643	1.643	1.744	1.744	1.786	1.882	1.952	2.072	2.340	2.406	2.540
h1	mm	1.115	1.115	1.182	1.182	1.282	1.282	1.312	1.370	1.415	1.531	1.776	1.794	1.898
h2	mm	655	655	697	697	743	743	750	771	796	841	948	949	992
Øk	mm	250	250	250	250	300	300	350	400	450	450	500	550	650
m	mm	1.537	1.537	1.580	1.580	1.682	1.682	1.762	1.847	1.922	2.012	2.298	2.377	2.492
n	mm	1.170	1.170	1.240	1.240	1.320	1.320	1.400	1.480	1.550	1.650	1.922	2.000	2.110
Counter-Pressure	mbar	0,8-1,2	1-1,5	2-2,5	2-2,5	2,5-3	3-3,5	4,5-5	5-5,5	5,5-6	5,5-6	6-6,5	6,5-7	7-7,5

Appendix C: Chiller Datasheet

PSC

Air Cooled Smart Chiller with Scroll Compressor

Air Cooled Smart Chiller with Scroll Compressor

PETRA’s Air-Cooled Smart chillers (PSC) with hermetic scroll compressors with R410a / R407c refrigerants, offer a wide range of sizes to meet customer requirements for different applications.
PETRA’s Smart chillers are designed to meet customer requirements by offering state of the art low sound, reliability, high energy efficiency and small physical footprints. The wide range of cooling capacities and flexible installation arrangement makes them easy to install and maintain.
PETRA’s Smart Chillers (PSC) are designed to be shipped as a complete factory package which are 100% test run in the factory. Unit capacities in this series range from 151 kW (43 Tons) to 1,343 kW (382 Tons) at 50Hz and from 179 kW (51 Tons) to 1565 kW (445 Tons) nominal tons at 60Hz with refrigerant R410a and from 144 kW (41 Tons) to 1,322 kW (367 Tons) at 50Hz and from 162 kW (46 Tons) to 1523 kW (433 Tons) nominal tons at 60Hz with refrigerant R407c. A wide choice of chiller capacities and options are available to meet most design requirements.
PETRA’s Smart Chillers PSC consist of highly efficient low-pressure drop coolers and high quality condenser coils with maximized airflow. Condenser coils are equipped with low noise fans with patented design fan and motor mounting.
PETRA’s Smart Chillers are equipped with an intelligent microprocessor controller to manage the unit’s performance for optimum efficiency at both full load and part load values.

Standard Features

- Welded structural C-channel base painted with mono component catalyzed primer sprayed paint.
- Base is equipped with welded brackets for heavy duty lifting lugs.

- Structural members are made from gauge 15 [1.8 mm (0.07 inch)] tubular cross members that are semi welded with stainless steel fasteners. All members & panels (side & roof) are painted with oven baked polyester electrostatic powder paint.
- High performance hermetic scroll compressor.
- Condenser coils are microchannel type (MCHE) or copper tubes copper aluminum type.
- All coils are air pressure tested by dry air up to 2,900 kPa (420 Psi) under water. They also undergo dry cleaning after manufacturing for optimum system cleanness.
- Condenser coils are covered with protective panels, to ensure uniform air distribution across the coil face area & provide additional protection for coil from weather elements.
- Condenser fans of the external rotor type with many attractive features such as space saving, compact design, optimum cooling, full speed controllability and low starting currents.
- High efficiency direct expansion (DX) shell and tube type coolers with inner grooved tubes to optimize the cooler’s efficiency.
- Coolers are tested and stamped for refrigerant side design pressure of 1,000 kPa (145 Psi) and for a maximum water side working pressure of 1,500 kPa (220 Psi).
- Liquid, discharge and suction pipes are all hard copper pipes. They are formed using automated CNC pipe bending machines in order to minimize pipe-brazed joints which in turn increases system reliability.
- Epoxy paint for all exposed copper piping system of the refrigeration circuit.
- Components of each refrigeration circuit include liquid line solenoid valve, liquid line shut off valve, liquid line moisture indicator sight glass, high safety pressure switch and replaceable core type filter.
- Unit is fully charged unit with R410a/R407c refrigerant.
- Electronic expansion valve: Electronically Operated Step Motor flow control valves, intended for the precise control of liquid refrigerant flow. Synchronized signals to the motor provide discrete angular movement, which translates into precise linear positioning of the valve piston. Easily interfaced with microprocessor based controllers.
- Compressor electronic current monitor and overload protection through controller
- Free terminal for remote ON/OFF connection.
- Free terminal for general alarm output.
- Control voltage is 220-240V for all components.
- Single point power connection for each electrical panel.
- Circuit breaker for each compressor.
- Starting contactors for compressors and condenser fan motors.
- ON/OFF switch for each compressor.
- Control circuit breaker for short circuit protection.
- Short cycling protection for compressors (time delay).
- Control transformer mounted & wired that shall supply all unit control voltage from main unit power supply to internal components such as (not limited to) solenoid valves, compressor motor protector, compressor crank case heater and microprocessor controller.
- Microprocessor controller for full management of chiller operation and safety circuits.
- Power supply monitor (phase failure relay) used to protect the power circuit against over or under voltage conditions and against phase loss or loss reversing conditions.
- Nema 3X with IP54 minimum enclosure standard electrical panel. Two separate panels, one for power & the other for control.
- Separate electrical box for condenser fan motors located on condenser side.