An-Najah National University

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Implementation of Pinch Technology in Local Industry as an Energy Management Tool

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DEDICATION

Our **parents**, you are the light of our life, the motivation of all our achievements and the source of our real happiness. Thank you so much for your unconditional love and support. We can’t make anything without you. You are our real treasure.

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Many thanks for our **lecturers** for all efforts to make us open minded engineers.

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ABSTRACT

Energy efficiency has become an important feature in the design of process plants especially with the rising cost of energy and the more stringent environmental regulations being implemented worldwide.

The energy sector in Palestine suffers from severe shortage and ambiguous future. Our industries and institutions suffers from bad energy management and bad efficiency as well. From this background, this research has started.

This study assesses the possibility of implementing the pinch principle to retrofit the energy recovery possibilities in food sector. Two factories located in Nablus city were selected for this study. The first one is Al-Arz ice cream factory and the other is Al-Safa dairy factory. Pinch concept was used to enhance the heat recovery between hot and cold streams with a heat exchanger network (HEN) as needed.

Al-Arz factory is one of the biggest ice cream producers in westbank, it has a capacity of 8 million liter of ice cream monthly. This study was made to focus on the milk pasteurization process as a big opportunity for energy saving.

Seven major scenarios were identified to reduce utility cost demand of heating and cooling process. These scenarios were designed based on changing the $\Delta Tmin$ starting with $\Delta Tmin = 5$°C and ending with $\Delta Tmin = 15$°C.

After comparing results obtained from the different scenarios, it was observed that the maximum HX capital cost was 2753 $NIS/year$, while the minimum total energy cost was 152057 $NIS/year$. Also the minimum HX capital cost was 1019$NIS/year$, while the maximum total energy cost was 73658 $NIS/year$.

A reference case called "Zero case" was used to benchmark with other scenarios to obtain the optimum heat recovery and savings. It was observed that the maximum total energy saving was 391991 $NIS/year$ and minimum total energy savings of 310816 $NIS/year$.

In **Al-Safa** factory, about 1700 $L/year$ of cheese is produced per year, about 80% of this amount is whey and disposed through sewage network. Whey in Al-Safa factory was taken as a case study for recovery of whey. Evaporation process was the main concern, it was studied to concentrate feed whey from 6.5% to 26% to be used in other food industry.

Six main energy saving scenarios were suggested to study the optimization of the evaporation process. Two of the scenarios were studied with single evaporator, while the other four were suggested to be applied with multiple effect evaporator.

After comparing results obtained from the different scenarios, it was observed that the maximum evaporator capital cost was 17417 $NIS/year$, in the 3-stage evaporation system with the minimum total energy cost was 6947 $NIS/year$ while the minimum evaporator capital cost was 8850$NIS/year$, with the maximum total energy cost was 19536 $NIS/year$ in the single evaporation system. The final results indicated that the 3 stage evaporation system is more effective and feasible to be adopted.

NOMENCLATURE

$\boldsymbol{HEN}$	Heat Exchanger Network	$\boldsymbol{A}$	Area
$\boldsymbol{HX}$	Heat Exchanger	$\boldsymbol{\Delta TIM}$	Log Mean Temperature Difference
ΔT_{min}	Minimum Temperature Difference	$\boldsymbol{NTU}$	Number of Transfer Unit
$\boldsymbol{Q}$	Heat Transfer Load	$\boldsymbol{L}$	Length
$\boldsymbol{USD}$	United states Dollar	$\boldsymbol{W}$	Width
$\boldsymbol{CP}$	Heat Capacity Flowrate	$\boldsymbol{Nc}$	Number of channels
$\boldsymbol{SPBP}$	Simple Pay Back Period	$\boldsymbol{A_c}$	Cross Sectional Area
$\boldsymbol{T_s}$	Supply Temperature	$\boldsymbol{d_e}$	Hydraulic Diameter
$\boldsymbol{T_t}$	Target Temperature	$\boldsymbol{U_p}$	Channel Velocity
$\boldsymbol{\Delta H}$	Enthalpy Change	$\boldsymbol{R_e}$	Renold Number
$\boldsymbol{U}$	Overall Heat Exchanger	$\boldsymbol{N_u}$	Nusselt Number
$\boldsymbol{w}$	Mechanical Work	$\boldsymbol{P_r}$	Prandtle Number
$\boldsymbol{c_p}$	Specific Heat at Constant Pressure	$\boldsymbol{h_p}$	Heat Transfer Coefficient
$\dot{m}$	Mass Flow Rate	$\boldsymbol{A_w}$	Annual Worth
$\boldsymbol{T}$	Temperature	$\boldsymbol{P_r}$	Present Worth
$\boldsymbol{TIM}$	Temperature Interval Method	$\boldsymbol{i}\%$	Interest Rate
$\boldsymbol{MER}$	Minimum Energy Requirements	$\boldsymbol{n}$	Number of Years
$\boldsymbol{T_{ho}}$	Output Temperature of Hot Stream	$\boldsymbol{\frac{L}{day}}$	Liter per day
$\boldsymbol{T_{hi}}$	Input Temperature of Hot Stream	$\boldsymbol{Mf}$	Mass flow rate of the feed whey
$\boldsymbol{T_{co}}$	Output Cold Temperature	$\boldsymbol{Mev}$	Mass flow rate of the evaporated whey
$\boldsymbol{T_{ci}}$	Input Cold Temperature	$\boldsymbol{Mc}$	Mass flow rate of the concentrated whey
$\boldsymbol{C_c}$	Cold Stream Heat Capacity	$\boldsymbol{Xf}$	The input feed whey concentration
$\boldsymbol{C_e}$	Hot Stream Heat Capacity	$\boldsymbol{Xc}$	The concentrated whey concentration
$\boldsymbol{Qe}$	Thermal load of the evaporator	$\boldsymbol{Tc}$	Temperature of the concentrated whey
$\boldsymbol{Tf}$	Temperature of the feed whey	$\boldsymbol{\lambda v}$	Latent heat of the evaporated whey
$\boldsymbol{Ms}$	Mass flow rate of steam consumption	$\boldsymbol{\lambda s}$	Latent heat of the steam
$\boldsymbol{Ue}$	The overall heat transfer coefficient of the evaporator	$\boldsymbol{Ae}$	The evaporator area
$\boldsymbol{Ts}$	Temperature of utility steam	$\boldsymbol{Qc}$	Thermal load of the condenser
$\boldsymbol{LMTD}$	Log mean temperature difference	$\boldsymbol{Tf, out}$	Temperature of the output feed stream from the condenser
$\boldsymbol{Tf, in}$	Temperature of the input feed stream to the condenser	$\boldsymbol{Uc}$	The overall heat transfer coefficient of the condenser
$\boldsymbol{Tv}$	The vapor temperature	$\boldsymbol{\lambda}$	Latent heat of vaporization

CONSTRAINS

1. *Thermodynamics constrains*

- **Temperature difference:** according to the second law of thermodynamics, the heat is transferred naturally from the high thermal reservoir to the low thermal reservoir. So, hot stream should be higher enough than cold stream to have sufficient driving force.

- **Amount of heat (C_P):** it`s the product of mass flow rate with constant specific heat. If the driving force was not enough, C_P should be compliant with the temperature difference to have an optimum driving force, the variation of constant pressure specific heat $c_p(\frac{kJ}{kg.K})$ with temperature was neglected and it was consider as constant value

- ΔT_{min}: it`s the minimum temperature difference between hot composite curve and cold composite curve. The optimum value of $\Delta T_{min}$ shouldn`t be zero in order to avoid infinity area of HX. If $\Delta T_{min}$is higher than the optimum, the process will depend more on the utility, and if it`s lower than the optimum, process will depend on the recovery and so larger area of the HX will be needed.

2. *Economical constrains*

- **Simple payback period (SPBP):** The payback period is the length of the time required to recover the cost of an investment. It`s is a useful indicator to decide whether to take a step towards the technology or not.

- **Heat Exchanger and evaporator area:** Capital investment cost is related directly to the HX and evaporator area. Whenever the area increases, the capital cost will increase too. The optimum area must be adopted in order to have the most effective heat recovery side by side with the most effective cost.

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CHAPTER 1: INTRODUCTION

Overview

Human population of the world keeps growing during the ages, as a result of this growth, the energy consumption increases too, it`s about 4 times faster than the population growth. (Balance, 2015) According to the big growth in energy consumption, the energy sources are depreciating quickly, by the time we will reach a point at which these sources will run out.

Global energy consumption has increased steadily for much of the twentieth century, particularly since 1950. In 2011, the world consumed 88 million barrels of oil per day (Statistical Review of World Energy, 2012) (institute, 2016)

As the demand for energy around the world grows, it causes many environmental changes with bad effects, like: air pollution, water pollution, climate change, global warming, deforestation, and ozone layer depletion. Also since the industrial revolution (1750-1850), the rate of CO_2 increased rapidly. The concentration of the CO_2 before this stage was (240-280) ppm, as for today`s, the level is 401ppm. To avoid a 2°C increase in earth temperature, the level should stay below 450ppm (CO2-earth, 2016). After rising more than 50 percent from 1990 to 2014, global energy-related CO2 emissions will likely peak around 2030 (ExxonMobil, 2016).

Engineers and scientists have made extensive efforts to search and find methods and alternatives to slow down energy consumption. They have concluded two main trends: cleaner production and energy efficiency. Cleaner, greener energy supplies may provide the cleanest supplies of needed energy. But energy efficiency is the best way to reduce energy consumption and electricity bills.

Energy efficiency improvements over the last 25 years have saved a cumulative USD 5.7 trillion in energy expenditures. It generates multiple benefits for governments, businesses and households, including greater energy security from reduced dependence on energy imports and billions of tonnes of greenhouse gas emissions reductions. ((IEA), 2015)Energy efficiency will play a huge role in slowing the growth in global demand, as energy use per unit of economic output is likely to fall by 40 percent. (ExonMobil, 2016)This trend includes energy integration, energy recovery, and pinch technology which will be discussed in this study.

Definition

Pinch analysis is a systematic methodology (based on thermodynamic principles) for **reducing energy consumption of different processes** (especially in thermal ones) by optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as "process integration", "heat integration", and "energy integration".

Pinch technology can be applied in many fields and industries especially ones that depend on thermal operations. Wherever energy is used, there is a potential opportunity of this technology. Also it can be applied effectively in the petrochemical sectors and in the mainstreams of chemical engineering. Heating and cooling processes is another applicable field.

Heat Exchangers

Heat Exchangers overview

A heat exchanger is a device that is used to transfer thermal energy. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multicomponent fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Common examples of heat exchangers are: plate heat exchangers, shell and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers. (Exchangers, n.d.).

Plate HX was considered because of many reasons which will be clarified in the HX design section.

Plate Heat Exchanger

A plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. This has a major advantage over a conventional heat exchanger in that the fluids are exposed to a much larger surface area because the fluids spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of the temperature change. The heat transfer surface consists of a number of thin corrugated plates pressed out of a high grade metal. The pressed pattern on each plate surface induces turbulence and minimizes stagnant areas and fouling. (Varghese et al. , 2014)

Plate heat exchanger was chosen because of some distinctive properties it has, like:

1. More economical than the other types.
2. Easier to maintain.
3. Can be used at low temperatures as $1℃$ compared with $5-10℃$ for shell and tube HX.
4. More flexible due to the extra plates.
5. More suitable with high viscose materials thus best-fitted with milk which is viscose fluid.
6. The temperature correction factor is normally higher with plate HX s the flow is true closer to true counter-current flow.
7. Fouling tends to be significantly less.

Stainless steel material was used in the plate HX because of some reasons, such as:

1. Stainless steel is known with its corrosion resistance.
2. It has good resistance for high-temperature.
3. It maintains excellent heat transfer properties, thus suitable product process.
4. It`s also resistance to fouling due to corrosion.
5. No contamination of product which is highly needed since we are dealing with food industry.
6. Widely available and easy to clean, and cheaper compared to other material.
7. More economical.

Heat Exchangers design

The design of new HX networks can be best executed by using the pinch method. Using the pinch method incorporates two important features: a) it recognizes that the most constrained part of the problem is the pinch region and b) designers are allowed to choose between the match options. The designer examines which hot streams can be matched to the cold stream by heat recovery. Every match brings one stream to its target temperature and the pinch separates the heat exchanger systems into two thermally independent regions, heat exchange networks above and below pinch temperature. When the heat recovery is maximized the remaining thermal needs are supplied by external heat utility (Rokni, 2016)

Due to the wide utilization of heat exchangers in industrial processes, their cost minimization is an important target for both designers and users. Traditional design approaches are based on iterative procedures which gradually change design parameters until a satisfying solution, which meets the design specifications, is reached. However, such methods, besides being time consuming, do not guarantee the reach of an economically optimal solution. Therefore, in this report, calculations of annualized Capital Cost and annualized Energy Cost to obtain the total cost curve that optimized ΔT_{min} can be found from it to determine the area needed to design the proper HX, as will be discussed in the Economical analysis and monetary saving section.

It worths to mention that the pressure drop value was neglected according to the small value of mass flow rate and the nature of plate heat exchanger.

Evaporators

Evaporator is a device used to turn liquid in to its gaseous form. It has many types, like: natural/forced circulation evaporator, falling film evaporator, rising film evaporator, and other types.

An evaporator can be used in many applications, like air conditioning system, and it can also be used to remove water or other liquids from mixture. This process is widely used to concentrate foods and chemicals. Food industry is the main focus in this study, and the falling film one is used.

Falling film evaporator

Falling film evaporator is a vertical shell-and-tube heat exchanger, with a laterally or concentrically arranged centrifugal separator. The liquid to be concentrated is supplied to the top of the heating tubes and distributed in such a way as to flow down the inside of the tube walls as a thin film. The liquid film starts to boil due to the external heating of the heating tubes and is partially evaporated as a result. The downward flow, caused initially by gravity, is enhanced by the parallel, downward flow of the vapor formed.

Whey concentration process

Milk has two major components appear during processing, which are whey and crudes. In this project, the whey concentration will be studied and analyzed from financial and energy point of view.

Whey is the liquid portion of the milk that separates from the curds during the process of making either cheese or labaneh. It contains proteins, fats, carbohydrates, vitamins, and minerals. The concentration process occurs by pushing the liquid portion of milk through an evaporator creates whey protein. The material left behind is thickened or dried, and concentrated whey protein is formed. Concentrated whey contains varying amounts of fat and carbohydrates in the form of lactose. The percentage of protein varies from about 30% to about 80%, and includes a variety of protein sub fractions, of which has significant biologic activity and health benefits.

Industrial situation and Potential Opportunities

There`s three main sectors in Palestine: Residential and Commercial sector, Transportation sector, and Industrial sector.

In this study, our focus was on the thermal energy usage. As known, the industrial sector is one of the biggest consumers of this energy. It`s important to mention that the industrial sector represents 12% of the total local economy, according to the statistics of 2013. (الرنتيسي, 2015)
There`s several types of industries in Palestine, like: medicine industry, building materials industry, plastic industry, clothes industry, beverage industry, and food industry. Food industry has played an important role, it has contributed more than 24% of the local production value (PALTRADE, 2016), and about 22% of the total Palestinian exports, where the Palestinian food exports reached to $ 170 million during the year 2012 as the second export sector after stone and marble, so the food industry takes its importance because of its ability to export and fill a large part of the Palestinian consumer needs ((PFIU), 2015). The food industry was the main concern of this study.

Economical analysis and monetary savings

In a realistic competitive environment, projects are implemented based upon their economic incentives. Therefore, one of the most important steps in an energy study is to examine the heat recovery projects from an economic point of view. The capital cost of the proposed projects is estimated and the potential monetary savings are calculated. Based on the cost benefit analysis results, some of the alternatives could be changed; sacrificing savings for capital, i.e., an optimization of savings vs. capital is performed. At the final stage of a study, a clear understanding of the opportunities for energy and capital savings, financial benefit, and the actions required to achieve them will be understood clearly. (Theodora et al., 2015)

Objectives

1. Understand a new concept of energy management tool called "Pinch Technology"

2. Investigate the principles of pinch technology such as: ΔT_{min}, composite curve, heat exchanger network (HEN)

3. Perform necessary calculations for optimizing HEN in Al-Arz factory case.

4. Conduct economical analysis based on maximizing energy recovery, minimizing utility needs with minimum HX cost.

5. Investigate the principles of whey concentration process in Al-Safa factory case.

6. Perform necessary calculations for optimizing single and multiple effect evaporators in Al-Safa factory.

7. Perform different feasibility calculations.

CHAPTER 3: LETRATURE REVIEW

While oil prices continue to climb, energy conservation remains the prime concern for many process industries. The challenge every process engineer faced is to seek answers to questions related to their process energy patterns. Pinch technology came as one of the answers to help solving energy consumption and savings issues.

Charles Hohmann submitted a doctoral thesis (1971) on industrial energy conservation using heat exchange networks (Raymond R., 2012). After that year, Bodo Linnhoff a Ph.D. student from the corporate laboratory, Imperial Chemical Industries Limited, ICI, under the supervision of Professor John Flower, University of Leeds, hit the mainstream (in pinch technology), that was in the late 1970s and early 1980s, Linnhoff and coworkers brought Pinch Analysis to the world.

In late 1978, Linnhoff devised a new approach to describe energy flows in process heat exchanger networks. It was an introduction of thermodynamic principles into what was then called “process synthesis” and heat-exchanger network design.

Today, it is called pinch technology and has an established industrial track record. There are over 500 projects undertaken worldwide. The BASF Company alone has undertaken over 150 of these projects. They have been able to achieve a saving of over 25% of energy in their main factory at Ludwigshafen, Germany, by adopting this technique. As at 1997, there were 16 multinational companies in a process integration research consortium coordinated by UMIST Manchester UK, supporting new pinch technology developments. Some of these are well known companies such as M.W. Kellogg USA, Elf France, Mobil UK and ICI UK (Mubarak , Al- Kawari, 2000).
Liu Sun, Xionglin Luo, and Ye Zhao has published a study about Synthesis of multipass heat exchanger network with the optimal number of shells and tubes based on pinch technology (Lin Sun et al., 2015).
Also there`s a study for Saba Valiani, Nassim Tahouni, and M. Hassan Panjeshahi talks about Optimization of pre-combustion capture for thermal power plants using Pinch Analysis (Saba Valiani et al., 2016).

CHAPTER 4: METHODOLOGY

Energy saving in process plant design has essentially been trial and error procedure between changes in structure and simulation until satisfactory energy consumption reductions are achieved. Energy saving reflects itself in many ways, for example reduced fuel consumption or reduced maintenance cost due to lower load on various items of plant equipment or have the optimum heat recovery from the heat exchanger network.

The objective of this study is to examine the feasibility of implementation the pinch principle on two local industries through optimizing the HEN.

To achieve this goal, in Al-Arz case, the factory were visited and data were collected, where in Al-Safa factory, data were collected from previous study. Several scientific papers of related fields were read and analyzed, the Microsoft excel was used to build different models to perform advanced economical and thermal calculations based on thermo-economical principle. Final results were analyzed to obtain the final recommendation.

CHAPTER 5: THEORITICAL BACKGROUND

Pinch analysis is a means of optimizing an industrial process by using the heat energy from the streams instead of using external heating and cooling methods (heat exchanger, furnace, cooler, etc.) to increase thermal efficiency of the plant and minimize energy costs. However, in any pinch analysis problem, whether a new project or a retrofit situation; a well-defined stepwise procedure is followed. Additional activities such as simulation and data modification occur as the analysis proceeds and some iteration between various steps is always required.

The steps of the graphical method are included below:

1. **Identification of Hot, Cold, and Utility streams in the process:**
    - Hot streams are those which must be cooled
    - Cold streams are those that must be heated
    - Utility streams are used to heat or cool streams` processes

2. **Thermal data extraction for the streams and utilities:**

For each hot, cold, and utility stream identifications, the following thermal data should be extracted:

A. Supply Temperature **($\boldsymbol{T_s}$(°C)):** the temperature at which the stream is available

B. Target Temperature $\boldsymbol{T_t}$(°C)**:** the temperature at which the stream must be taken to

C. Heat Capacity Flow Rate($\boldsymbol{C_p}\left(\frac{\boldsymbol{kW}}{°\mathrm{C}}\right)$): a constant heat capacity over the operation range is assumed.

D. Enthalpy Change($\Delta\boldsymbol{H}$)

3. **ΔT_{min} value selection:**

   Minimum heat transfer driving force must always be allowed for a feasible heat transfer design. The temperature of any hot or cold stream at any point in heat exchanger must always have a minimum temperature difference (ΔT_{min}), this ΔT_{min} value represents the bottleneck, and its value is determined by the overall heat transfer coefficient (U) and the geometry of heat exchanger. It is very important to choose optimum value of ΔT_{min}, if smaller value of ΔT_{min} is chosen the required area will rise, and if a higher value of ΔT_{min} is selected, the heat recovery in the Heat Exchanger (HX) decreases and the demand for external utility increases.

4. **Composite curves construction:**

   Composite Curves consist of temperature **(T)** – Enthalpy **(ΔH)** profile. The heat availability in the process called Hot Composite Curve and the heat demands in the process called Cold Composite Curve. They are plotted together in a graphical representation.

   Combined Composite Curves are used to predict targets for:

   - Minimum energy (for both hot and cold utility) required.
   - Minimum network area required
   - Minimum number of exchangers units required

5. The point where the two composite streams touch or very close to each other is called " Pinch point"
6. The region of overlap between the two streams determines the amount of heat recovery possible
7. The part of the cold stream that extends beyond the start of the hot stream cannot be heated by recovery and requires steam and it is the minimum hot utility or energy target
8. The part of the hot stream that extends beyond the start of the cold stream cannot be cooled by heat recovery and requires cooling water and it is the minimum cold utility

A representation of a combined composite curve is shown in the figure (1) below:

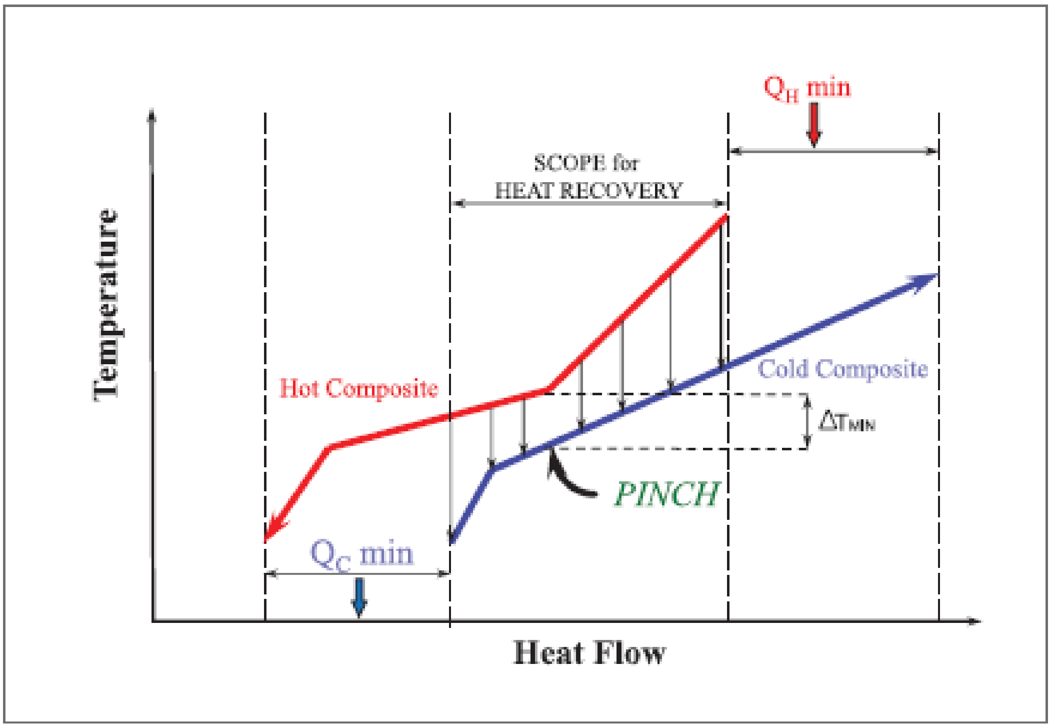

Figure 1: Composite Curves Reprisentation

Composite Curve Specifications:

Heat capacity flow rate (C_P ($\frac{kW}{°C}$): the product of flow rate ($\dot{m}$) in ($\frac{kg}{s}$) and specific heat (C_P) in ($\frac{kJ}{kg.°C}$)

$$CP = m \times Cp$$

Enthalpy Change (ΔH**)**: associated with a stream passing through the exchanger.

It is giving by the first law of thermodynamics:

First law of energy (Energy is conserved):

$$\Delta H = Q \mp W$$

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

$$w = 0$$

The first law simplified to: $(\Delta \boldsymbol{H} = \boldsymbol{Q})$, where $\boldsymbol{Q}$ represents heat supply or demand associated with the stream. $\boldsymbol{Q}$ is giving by the relationship:

$$\boldsymbol{Q} = \boldsymbol{CP} \times (\boldsymbol{Ts} - \boldsymbol{Tt})$$

Composite curve creation:

As mentioned previously, the plotting will be a relation between the temperature $\boldsymbol{T}$ (°C) and enthalpy change $\Delta \boldsymbol{H}$ $(\boldsymbol{kW})$

First each stream will be taken alone with supply temperature $(\boldsymbol{Ts})$, target temperature$(\boldsymbol{T_t})$, mass flow rate$(\dot{m})$, and heat capacity flow rate$(\boldsymbol{C_P})$**.** They will be plotted on the T-H diagram according to the mathematical relations for $\Delta \boldsymbol{H}$.

After having all curves for all streams plotted, hot streams curves will be gathered in one curve, and cold streams curves will be gathered in another curve. In general, any stream with a constant heat capacity flow rate $(\boldsymbol{C_P})$**.** The value is represented on a diagram by a straight line running from stream supply temperature to stream target temperature. When there is a number of hot and cold composite curves simply involves the addition of the enthalpy changes of the stream in the respective temperature intervals to get one hot-cold diagram, the process will be composite (the naming of the composite curves); i.e.: the enthalpy change for all streams will be cumulative addition to previous $\Delta \boldsymbol{H}$ value, so we can get the hot or cold stream curve. This can be summarized in figure 2.

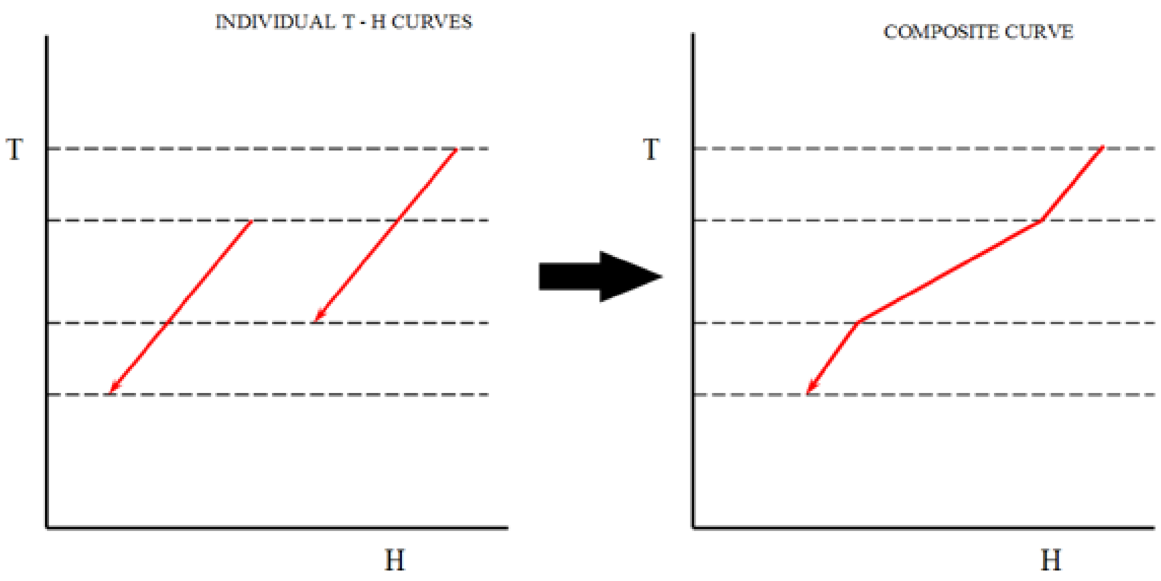

__Figure 2:__ reprisentation of a composite curve from hot and cold streams

Because of the "kinked" nature of the composite curves, they approach each other most closely at one point defined as the minimum approach temperature ($\Delta \boldsymbol{T_{min}}$). It can be measured directly from the $T - H$ profiles as being the minimum vertical difference between the hot and cold curves.

This point of minimum temperature difference represents a bottleneck in heat recovery and is commonly referred to as the "Pinch Point".

Economical Analysis and Monetary Savings

Several options, as how to use the steam savings are identified, choice between the options depends on the economic analysis and other facility plans. The reduction of process steam demand can:

1. Leads to reduced purchased fuel consumption.
2. Be used to generate more power.
3. Facilitates increased production without a net increase in the steam usage.

In order to calculate the true monetary savings resulted from the heat recovery projects, it is important to identify the origin and the true cost of the steam savings.

Simple Pay Back Period index (SPBP)

Simple bay back period is another key concept that must be taken in consideration during economical analysis stage. SBPB is the length of the time required to recover the cost of an investment.

SBPB for this types of projects usually ranges between (2_5) years.

It can be calculated by using following formula:

$$\text{SBPB} = \frac{Initial\ Investment\ (NIS)}{Savings\ \left(\frac{NIS}{year}\right)}$$

Initial investment in this study is the total cost of Heat exchanger units (NIS). While the savings are the saved cost resulted when the HXs are used. In our study, it's the cost of the: $270kW$, $60kW$, $90\ kW$, $10\ kW$ instead of using utilities.

CHAPTER 6: CASE STUDY

In this project, two main cases were considered to be studied and analyzed due to the pinch concept analysis, in order to study the savings opportunities.

Case study 1: Al-Arz ice cream factory

Overview

Al-Arz factory was established in 1950 by Mohammad Anabtawi in Nablus in order to cool water and store food. It has been evolved to be the leader of the frozen products in Palestine. Since its establishment, it has been grew to be a successful producer of high quality ice cream products.

Al-Arz has started exporting in 2007 and Jordan was the first station. Two years later, it obtained the global food safety certificate HACCP as the first one who had this certificate in the ice cream and dairy sector in Palestine and Jordan.

With state of the art facilities and equipment along with a production capacity reaching up to 8 million liters of ice cream per month, the company aims to remain the leading ice cream producer in Palestine with a strong focus on increasing the availability within the MENA region and around the world, through investing in Palestine and abroad in distribution networks, operations and supply chains. Furthermore, satisfy customers with the company`s high quality products and continuously improve their product range to meet customer's needs. And finally, creating job opportunities in Palestine and abroad by attracting competent personnel from different scientific sectors. (Company, n.d.)

In order to achieve this vision and to keep competitive, Al-Arz has adopted different technologies like energy management to provide high quality products with a suitable cost. In this study, the ability of implementing the pinch technology in the factory and the possible saving related to it is examined.

The pinch technology strategy in this proposed study was applied mainly on the **pasteurization process.** Where milk is heated from the room temperature 25℃ to 80℃, held for 15 $seconds$, and then rapidly cooled down to 5℃.

Theoretical background

Plate Heat Exchanger Design: Working principle of plate heat exchanger:

Channels are formed between the plates and the corner ports are arranged so that the two media flow through alternate channels. The heat is transferred through the plate between the channels, and complete counter-current flow is created for highest possible efficiency. The figure below shows a plate heat exchanger. The corrugation of the plates provides the passage between the plates, supports each plate against the adjacent one and enhances the turbulence, resulting in efficient heat transfer. Plate heat exchanger is shown in figure 3.

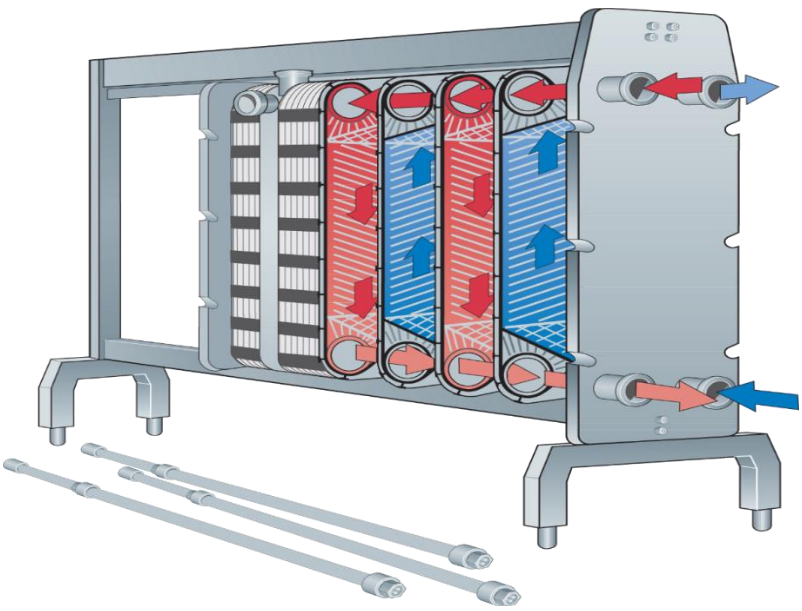

Figure 3: *Plate Heat Exchanger*

The following procedure is clarified to find the area of plate HX:

Heat transfer equation:

$$\boldsymbol{Q = A \times U \times \Delta T_{LM}}$$

$\boldsymbol{Q}$**:** The amount of energy that must be transferred by HX (W), it is already known.

$\boldsymbol{A}$**:** The area of HX (m^2), it will be found at the end of procedure.

$\boldsymbol{U}$**:** The overall heat transfer coefficient $(\frac{W}{m^2 .k})$, the first value will be assumed as a value between $(1000 - 5000)\frac{kW}{m^2 .c}$, then it will be recalculated according to the founded area.

$\Delta \boldsymbol{T_{LM}}$: log mean temperature difference (°C).

From the previous equation ($\boldsymbol{A}$) was founded, then all the plate HX specifications were extracted from the HX manual. These specifications are: number of plates, width and length of plates, and spaces between plates, corresponding to the founded area in order to calculate the accurate U value after it was assumed.

The following equations were used sequentially to achieve our goal:

$$\Delta \boldsymbol{T_{LM}} = \frac{[(\boldsymbol{Thi - Tco}) - (\boldsymbol{Tho - Tci})]}{\boldsymbol{ln}\,[(\boldsymbol{Thi - Tco})/(\boldsymbol{Tho - Tci})]}\ (°C)$$

$\Delta \boldsymbol{T_{LM}}$ Is used to determine the temperature driving force for heat transfer in flow systems.

Number of transfer units ($\boldsymbol{NTU}$):

$$\boldsymbol{NTU = \frac{T_o - T_i}{\Delta T_{LM}}}$$

$\boldsymbol{NTU}$: To calculate the rate of heat transfer in heat exchangers (especially counter current exchangers)

From the specifications of plate HX, the next requirements were founded:

Effective Plate Area for one plate:

$$A_{effic} = L \times W \ (m^2)$$

Number of Plates:

$$N = {}^{total\ heat\ transfer\ area}/_{effective\ area}$$

Note: the answer will be adjusted to the closest standard number of plates.

Number of channels per pass:

$$N_c = \frac{N - 1}{2}$$

Channel cross sectional area:

$$A_c = Plate\ spacing \times Plate\ width\ (m^2)$$

Hydrolic mean diameter:

$$d_e = 2 \times plate\ spacing, Plate\ spacing\ is\ in\ (mm)$$

channel velocity:

$$U_p = \frac{\dot{m}}{\rho \times Ac \times Nc} \left(\frac{m}{s}\right)$$

Where:

ρ: Density of the fluid ($\frac{Kg}{m^3}$)

Renold number: An important dimensionless quantity in fluid mechanics that is used to help predict flow patterns in different fluid flow situations.

$$(\boldsymbol{Re}) = \frac{\boldsymbol{\rho} \times \boldsymbol{up} \times \boldsymbol{de}}{\boldsymbol{\mu}}$$

Where:

$\boldsymbol{\mu}$: Viscosity of the fluid

$\boldsymbol{Nusselt\ number}$: The ratio of convective to conductive heat transfer across the boundary

$$\boldsymbol{Nu = 0.26 \times Re^{0.65} \times Pr^{0.4}}$$

$The\ calculated\ fin\ heat\ transfer\ coeffecient$:

$$\boldsymbol{hp} = \frac{\boldsymbol{Nu(k)}}{\boldsymbol{de}}$$

Where:

$\boldsymbol{K}$: Thermal conductivity of the material ($\frac{W}{m\ .k}$).

Now, the exact value of U will be calculated and compared with the iterated one,

$$1/_{U} = 1/_{hp,\,hot\ water} + 1/_{hp,\,cold\ water} + {}^{tp}/_{k,\,steel}$$

Note, if the calculated $\boldsymbol{U}$ is smaller than the assumption, just decrease the number of channels and recalculate on the new assumption.

Economical analysis

This section includes all equations used to perform different economic calculations as follows:

- **Energy Cost Analysis**

Since it`s needed to calculate the energy costs used, the following procedure steps were followed:

1. Working hours for the production per year (hr) were known from the factory.
2. Energy was calculated in (kWh)
3. Coefficient of performance (COP) was used for hot streams to calculate input energy and to find corresponding costs in (NIS)
4. Input energy was founded by using efficiency of the boiler (η), and the corresponding costs (NIS) was founded too for cold streams
5. The cost of hot and cold energy costs (NIS) was accumulated, which is the annualized energy costs

- **Cold side calculations**:

$$Q_{out} = \dot{m} \times Cp \times \Delta T$$

$$Q_{in} = \frac{Q_{out}}{\mu_{boiler}}$$

$Q(in)$: The input power consumed in heating process

$$Energy(kWh) = Q_{in} \times working\ hours(\frac{h}{year})$$

$$Energy\ (MJ) = Energy(kWh) \times 3.6(\frac{MJ}{kWh})$$

$$Kilograms\ of\ Disel = \frac{Energy\ (MJ)}{Heat\ content\ of\ disel\ \left(\frac{MJ}{kg}\right)}$$

$$Liters\ of\ Disel = \frac{Kilograms\ of\ Disel\ (kg)}{Density\ of\ disel\ (\frac{kg}{L})}$$

$$Cost(\frac{NIS}{year}) = Liters\ of\ Disel\ (L) \times cost\ of\ diesel(\frac{NIS}{L})$$

- **Hot side calculations:**

$$Q_{out} = \dot{m} \times C_p \times \Delta T$$

$$Q_{in} = \frac{Q_{out}}{COP_{boiler}}$$

$Q(in)$:The input power consumed in cooling process

$$Energy(kWh) = Q_{(input)} \times working\ hours(\frac{hr}{year})$$

$$Cost(\frac{NIS}{year}) = Energy(kWh) \times cost\ of\ (kWh)(\frac{NIS}{kWh})$$

- **Capital Cost Analysis**

HEN calculations were used to find the HXs cost needed for the process, also installation and maintenance cost of the HEN was founded. These costs were calculated to find the capital cost.

Usually, $Maintenance\ cost\ =\ 5\%\ of\ the\ installation\ cost\ (NIS)$

$$Capital\ cost =\ HXs\ cost\ +\ installation\ cost\ + maintenance\ cost\ (NIS)$$

Capital cost was annualized by using the following equation:

$$Annual\ cost\ \ =\ Capital\ cost\ (A/P, i\%, n)$$

Where;

$\boldsymbol{A\_w}$: Annual worth

$\boldsymbol{P}$: Present worth

$\boldsymbol{i}$%: Interest rate

$\boldsymbol{n}$: Number of years (HX life time)

- **Total Cost Analysis**

$$Total\ Cost\ = Energy\ Cost + \ Capital\ Cost$$

All the calculations based on the following properties listed in Table (1) below:

Table 1: Basic properties and values used in several economic calculations in the report

$Working\ hour$	3200 $hr/year$
$Milk\ flow\ rate$	2800 L/h
$Density\ of\ \ Diesel$	0.832 $kg/\ L$
$Heat\ content\ of\ Diesel$	45 $MJ\ /\ kg$
$Boiler\ Efficiency$	85%
$Working\ Hour$	2496 $hour/\ \ year$
$Price\ of\ Diesel$	5.5NIS/L
COP	3.5
$Electricity\ tariff$	0.6134 NIS/kWh

Energy analysis for adopting a heat recovery system:

All the following scenarios based on the composite curve defined previously and illustrated for Al-Arz in figure (4) below. Both the hot and cold streams have the same mass flow rate adopted in the factory. As a result, the distance between streams is parallel as shown in the following figure. Also, $\Delta Tmin$ increased at the same ratio in all scenarios.

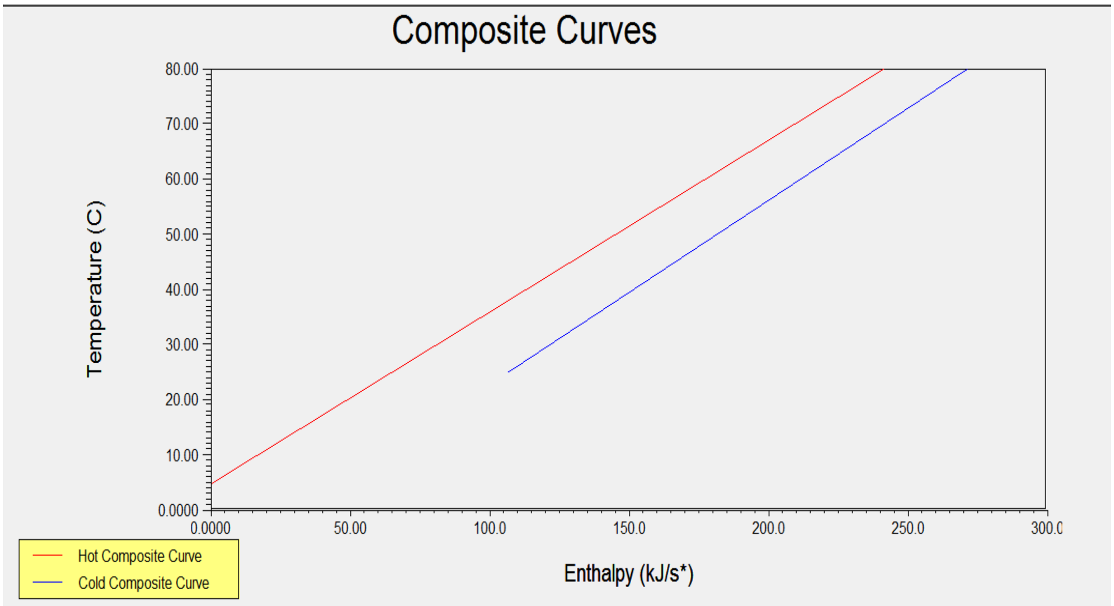

Figure 4: Composite Curve of Al-Arz factory streams

Scenarios to reduce the utility requirement:

The location of the pinch point is the key value for suggesting pertinent modifications of the process. Seven major scenarios have been identified in this section based on changing ΔT_{min} value between the two major streams which lead to change the output temperature of the hot stream side by side with the cold stream. While the input temperature of both streams (hot and cold) was constant in all scenarios.

In each of the following scenarios, the effect of changing ΔT_{min} value on the investment of a well identified heat exchanger and reducing of the utility requirements was studied.

The zero scenario (Reference Case):

In the reference case, all energy demand is supplied by the utilities without installing any HX, the total energy cost of this situation is $\mathbf{465650}\ \boldsymbol{NIS/year}$ (the cold stream makes total utility cost of $\mathbf{336423}\ \boldsymbol{NIS/year}$, while the hot makes a total of $\mathbf{129226}\ \boldsymbol{NIS/year}$**)**, table (2) and table (3) detailed these value for both hot and cold streams:

Table 2: Cold stream profile data

$Q_{output}(kW)$	169
$Q_{input}(kW)$	199
$Energy(kWh)$	636235
$Energy(MJ)$	2290447
$Kilograms\ of\ Diesel$	50899
$Liters\ of\ Diesel$	61176
$cost\ (NIS/year)$	336470

Table 3: Hot stream profile data

$Q_{output}(kW)$	230
$Q_{input}(kW)$	65.8
$Energy(kWh)$	210672
$cost\ (NIS/year)$	126403

Scenario 1: $\Delta T_{min} = \mathbf{5}$ ℃

A simplification of the heat exchanger`s streams is shown in figure (5) below:

Figure 5: The main streams at ΔTmin =5 ℃

The results of the first scenario are illustrated in table (4) below:

Table 4: The maim results at ΔT_{min}=5 ℃

$Q\ (kW)$	153
$U(kW/m^2.℃)$	267
$A(m^2)$	114
$Plate\ number$	351
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	24827
$Energy\ required\ by\ the\ boiler\ (kWh/year)$	57831
$Energy\ cost\ \ (NIS/year)$	30584
$Energy\ required\ by\ the\ chiller\ \ (kWh/year)$	70224
$Energy\ cost\ (NIS/year)$	43075
$Total\ energy\ cost\ (NIS/year)$	73658
$SPBP\ (year)$	0.0633

By comparing the amount of energy required by the utility between this scenario and the original one, it`s noticed that the total amount of the required energy was reduced from $\mathbf{846818\ kWh/year}$ to $\mathbf{128055\ kWh/year}$ and the total cost of the required energy was reduced from $\mathbf{465650\ NIS/year}$ to $\mathbf{73659\ NIS/year}$. The total savings in energy equals to $\mathbf{391991\ NIS/year}$

Scenario 2: $\Delta T_{min} = \mathbf{6}$℃

The heat exchanger streams of the second scenario are shown in figure (6) below:

Figure 6: The main streams at ΔT_{min} =6 ℃

The results of the second scenario are shown in table (5) below:

Table 5: The maim results at ΔT_{min}=6 ℃

$Q\ (kW)$	147
$U(kW/m^2.$℃$)$	395
$A(m^2)$	62
$Plate\ number$	191
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	20332
$Energy\ required\ by\ the\ boiler\ (kWh/year)$	69398
$Energy\ cost\ \ (NIS/year)$	36700
$Energy\ required\ by\ the\ chiller\ (kWh/year)$	73033
$Energy\ cost\ (NIS/year)$	44798
$Total\ energy\ cost\ (NIS/year)$	81498
$SPBP\ (year)$	0.053

By comparing the amount of energy required by the utility between this scenario and the zero scenario, it's noticed that the total amount of required energy was reduced from $\mathbf{846818}\ \boldsymbol{kWh/year}$ to $\mathbf{142431}\ \boldsymbol{kWh/year}$ and the total cost of required energy was reduced from $\mathbf{465650}\ \boldsymbol{NIS/year}$ to **81498 NIS/ year**. With total energy savings of $\mathbf{384152}\ \boldsymbol{NIS/year}$.

Scenario 3: ΔT_{min} = **7**℃

The heat exchanger streams of the third scenario are simplified in figure (7) below:

Figure 7: The main streams at ΔT_{min}= 7 ℃

The results of the second scenario are shown in table (6) below:

Table 6: The maim results at ΔT_{min}= 7 ℃

$Q\ (kW)$	144
$U(kW/m^2.°C)$	539
$A(m^2)$	38
$Plate\ number$	117
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	17437
$Energy\ required\ by\ the\ boiler\ (kWh/year)$	80964
$Energy\ cost\ \ (NIS/year)$	428178
$Energy\ required\ by\ the\ chiller\ (kWh/year)$	75842
$Energy\ cost\ (NIS/year)$	46521
$Total\ energy\ cost\ (NIS/year)$	89339
$SPBP\ (year)$	0.046

By comparing the amount of energy required by the utility between this scenario and the original scenario, it`s noticed that the total amount of required energy was reduced from $\mathbf{846818}\ \boldsymbol{kWh/year}$ to $\mathbf{156806}\ \boldsymbol{kWh/year}$ and the total cost of required energy was reduced from $\mathbf{465650}\ \boldsymbol{NIS/\ year}$ to $\mathbf{89339}\ \boldsymbol{NIS/\ year}$. With total savings in energy of $\mathbf{376311}\ \boldsymbol{NIS/year}$

Scenario 4: ΔT_{min} = **8** ℃

The heat exchanger streams of the fourth scenario are simplified in figure (8) below:

Figure 8: The main streams at ΔT_{min} =8 ℃

The results of the fourth scenario are summarized in table (7) below:

Table 7: The maim results at ΔT_{min} =8 ℃

$Q\ (kW)$	142
$U(kW/m^2.℃)$	690
$A(m^2)$	26
$Plate\ number$	79
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	15494
$Energy\ required\ by\ the\ boiler\ (kWh/year)$	92530
$Energy\ cost\ \ (NIS/year)$	48934
$Energy\ required\ by\ the\ chiller\ \ (kWh/year)$	78651
$Energy\ cost\ (NIS/year)$	48244
$Total\ energy\ cost\ (NIS/year)$	97179
$SPBP\ (year)$	0.042

After comparing the amount of energy required by the utility in this scenario and the zero scenario, it`s noted that the total amount of required energy was reduced from $\mathbf{846818}\ \boldsymbol{kWh/year}$ to $\mathbf{171181}\ \boldsymbol{kWh/year}$ and the total cost of required energy was reduced from $\mathbf{465650}\ \boldsymbol{NIS/year}$ to $\mathbf{97179}\ \boldsymbol{NIS/\ year}$. With total energy savings of $\mathbf{368471}\ \boldsymbol{NIS/\ year}$

Scenario 5: ΔT_{min} = **9** ℃

The heat exchanger streams of the fifth scenario are simplified in figure (9) below:

Figure 9: The main streams at ΔTmin=9 ℃

The results of the fifth scenario are shown in table (8) below:

Table 8: The main results at ΔT_{min} =9 ℃

$Q\ (kW)$	139
$U(kW/m^2.℃)$	865
$A(m^2)$	18
$Plate\ number$	55
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	13951
$Energy\ required\ by\ the\ boiler\ (kwh/year)$	104097
$Energy\ cost\ \ (NIS/year)$	55051
$Energy\ required\ by\ the\ chiller\ \ (kWh/year)$	81460
$Energy\ cost\ (NIS/year)$	49967
$Total\ energy\ cost\ (NIS/year)$	105018
$SPBP\ (year)$	0.038

After comparing the amount of energy required by the utility between this scenario and the zero, it`s noted that the total amount of required energy was reduced from $\mathbf{846818}\ \boldsymbol{kWh/year}$ to $\mathbf{185557}\ \boldsymbol{kWh/year}$ and the total cost of required energy was reduced from $\mathbf{465650}\ \boldsymbol{NIS/\ year}$ to $\mathbf{105018}\ \boldsymbol{NIS/\ year}$, total savings of energy are $\mathbf{360632}\ \boldsymbol{NIS/\ year}$

Scenario 6: ΔT_{min} **= 10** ℃

The heat exchanger`s streams of the sixth scenario are simplified in figure (10) below:

Figure 10: The main streams at ΔT_{min} =10 ℃

The results of the sixth scenario are shown in table (9) below:

Table 9: The main results at ΔT_{min} =10 ℃

$Q\ (kW)$	136
$U(kW/m^2.℃)$	1071
$A(m^2)$	13
$Plate\ number$	39
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	12671
$Energy\ required\ by\ the\ boiler\ (kWh/year)$	115663
$Energy\ cost\ \ (NIS/year)$	61168
$Energy\ required\ by\ the\ chiller\ \ (kWh/year)$	84269
$Energy\ cost\ (NIS/year)$	51690
$Total\ energy\ cost\ (NIS/year)$	112858
$SPBP\ (year)$	0.035

With comparing the amount of energy required by the utility between this scenario and the zero, it`s observed that the total amount of required energy was reduced from $\mathbf{846818}\ \boldsymbol{kWh/year}$ to $\mathbf{199932}\ \boldsymbol{kWh/year}$ and the total cost of required energy was reduced from $\mathbf{465650}\ \boldsymbol{NIS/\ year}$ to $\mathbf{112858}\ \boldsymbol{NIS/\ year}$. Total energy savings of this scenario equals to $\mathbf{352792}\ \boldsymbol{NIS/\ year}$

Scenario 7: $\Delta T_{min} = \mathbf{15}$℃

The heat exchanger`s streams of the last scenario are drawn in figure (11) below:

Figure 11: The main streams at ΔT_{min} =15 ℃

The results of the final scenario are illustrated in table (10) below:

Table 10: The main results at ΔT_{min} =15 ℃

$Q\ (kW)$	125
$U(kW/m^2.℃)$	2322
$A(m^2)$	4
$Plate\ number$	11
$Capital\ cost\ of\ heat\ exchanger\ (NIS)$	9249
$Energy\ required\ by\ boiler\ (kWh/year)$	173495
$Energy\ cost\ \ (NIS/year)$	91752
$Energy\ required\ by\ chiller\ \ (kWh/year\ )$	98314
$Energy\ cost\ (NIS/year)$	60306
$Total\ energy\ cost\ (NIS/year)$	152057
$SPBP\ (year)$	0.029

After comparing the amount of energy required by the utility between this scenario and the original, it's noticed that the total amount of required energy was reduced from $\mathbf{846818}\ \boldsymbol{kWh/year}$ to $\mathbf{271809}\ \boldsymbol{kWh/year}$ and the total cost of required energy was reduced from $\mathbf{465650}\ \boldsymbol{NIS/year}$ to $\mathbf{152057}\boldsymbol{NIS/year}$. The total energy savings in this scenario equals $\mathbf{310816}\ \boldsymbol{NIS/year}$.

Main conducted results for Al-Arz proposed Case:

According to the main results obtained from previous scenarios, it's obvious that with every change in $\Delta T_{min,}$ the other variables also changes, some of them increase while the other decrease, as shown in table (11) below.

The capital cost was performed based on the capital cost flat plate equation:

$$Capital\ cost = 1100 + (850 \times A^{0.4})\$$$ (Sinnott ،2005)

The utility costs are consequently higher from scenario to another while the investment cost for heat exchanger decreases. The greatest change is observed between scenario 1 and 2.

Table 11: The final results from each scenario

$\Delta \boldsymbol{T_{min}}$(°C)	$\boldsymbol{A}(\boldsymbol{m^2})$	$\boldsymbol{Capital\ Cost}$ $(\frac{NIS}{Year})$	$\boldsymbol{Energy\ Cost}$ $(\frac{NIS}{Year})$	$\boldsymbol{Total\ Cost}$ $(\frac{NIS}{Year})$	$SPBP$ $(year)$
5	114	2735	73659	76394	0.063
6	62	2240	81499	83739	0.053
7	38	1921	89339	91260	0.046
8	26	1707	97178	98885	0.042
9	18	1537	105018	106555	0.038
10	13	1396	112858	114254	0.035
15	4	1019	152057	153076	0.029

In addition to the obtained savings from each scenario compared to the zero case as clarified previously. Another comparison between the previous scenarios itself based on the decreasing in capital cost and increasing in utility demand can be summarized in term of percentage values as listed in table (12).

Table 12: Comparison between energy saving scenarios

$\boldsymbol{Scenario}$	$\boldsymbol{Capital\ Cost\ Changes}$	$\boldsymbol{Energy\ Cost\ Changes}$
1 *to* 2	18%	10.80%
2 *to* 3	14.20%	9.60%
3 *to* 4	11.14%	8.85
4 *to* 5	10%	8%
5 *to* 6	9%	7.50%
6 *to*7	27%	35%

As mentioned previously, the greatest change is observed between scenario 1 and 2, which is obvious in table (12) above.

The following curves shows relations between several parameters:

Figure (12) clarifies the variations of the heat exchanger area of each scenario according to the change in ΔT_{min} value, and it's clear that as the ΔT_{min} increases, the HX area decreases.

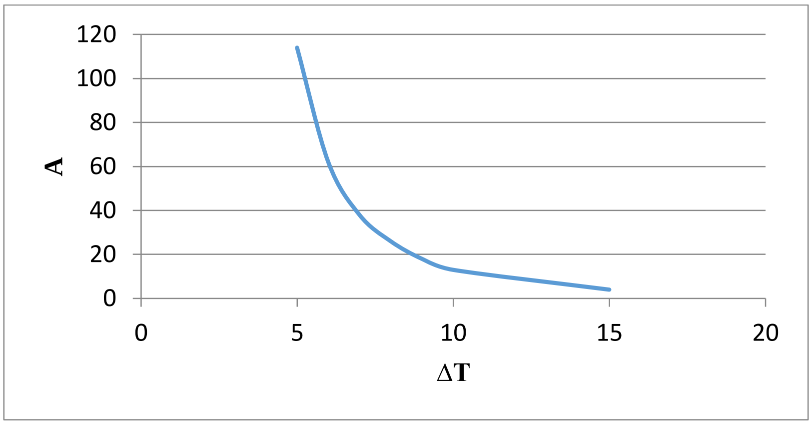

Figure 12: Temperature difference vs. HX area

The next graph illustrates the relationship between the heat exchangers areas and their costs:

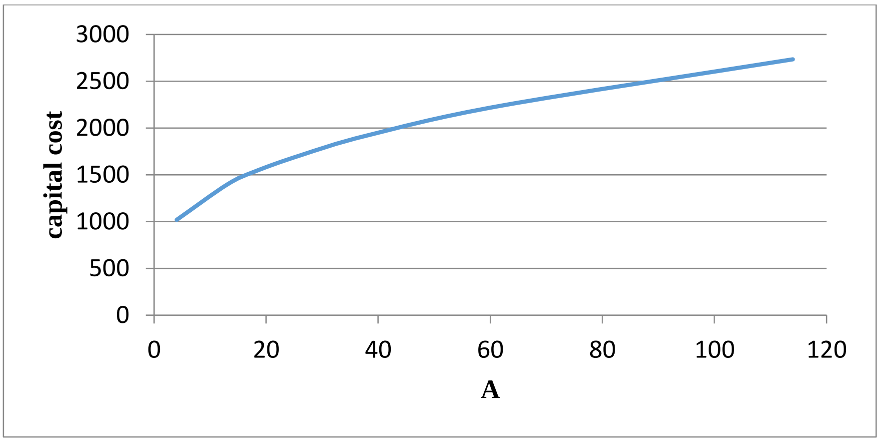

Figure 13: HX area vs. Capital Cost

As the curve shows, the capital cost or the purchasing cost increases with the area of the HX.

The relations between ΔT_{min} and capital cost, energy cost, and total cost are clarified in figures (14), (15), and (16) bellow:

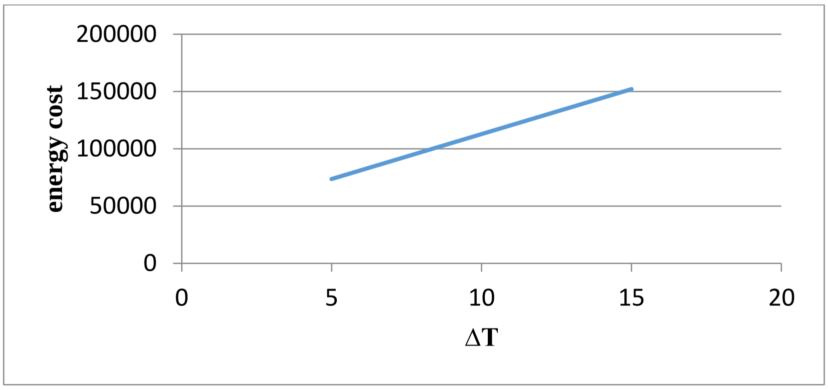

Figure 14: Minimum teperature difference vs. Energy cost

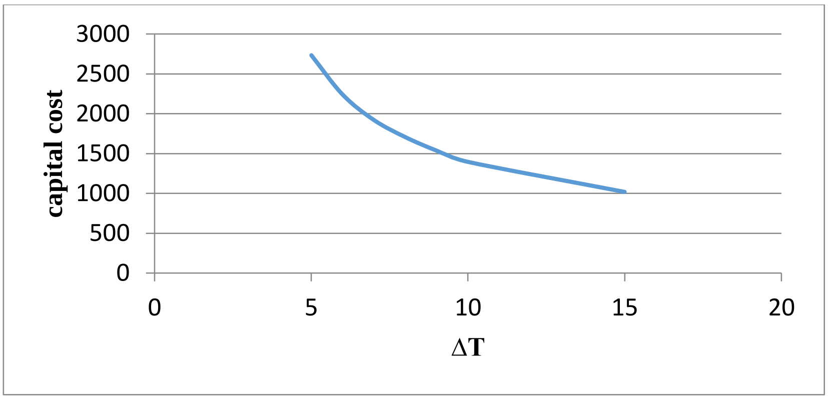

Figure 15: Minimum teperature difference vs. Capital cost

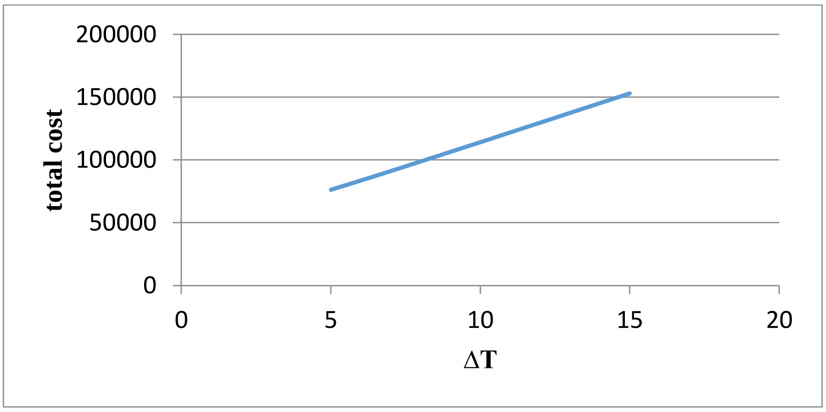

Figure 16: Minimum teperature difference vs.Total cost

When the value of ΔT_{min} increases, the energy cost also increases; while the heat exchanger cost decreases, however the total cost strongly affected by the energy cost as a result of its high price comparing with the capital cost of the heat exchanger.

It worths to mention that cooling tower was suggested to improve the recovery process in the system, and it was analyzed from energy and economic point of view. The next section explains the working principle of the cooling tower, and the possibility of using it.

Cooling Tower

Working principle

A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. The type of heat rejection in a cooling tower is termed "evaporative" in that it allows a small portion of the water being cooled to evaporate into a moving air stream to provide significant cooling to the rest of that water stream. The heat from the water stream transferred to the air stream raises the air temperature and its relative humidity to 100%, and this air is discharged to the atmosphere.

Common applications for cooling towers are providing cooled water for air-conditioning, manufacturing and electric power generation.

Cooling tower as a proposed modification in Al- Arz factory proposed case

Al-Arz factory has a cooling tower with a capacity of $\boldsymbol{7cube/day}$ and output water temperature of $\mathbf{23}$℃, this tower was proposed as an alternative to be studied in this project, and it was expected to make further cooling of the hot stream.

Thermal Analysis:

The following calculations have been done to determine its feasibility. Energy balance equations between milk and water were conducted to get the temperature of the milk out of the heat exchanger (used in the cooling process from cooling tower) as the following:

$$\Delta T = 10℃$$

$$\dot{Q}cooling\ water = \dot{Q}milk$$

$$(\dot{m} * cp * (To - Ti))_{water} = (\dot{m} * cp * (Ti - To))_{milk}$$

$$0.081 * 4.18 * (32 - 23) = 0.77 * 3.9 * (35 - To)$$

From the above equation: $\boldsymbol{To} = \mathbf{34}$℃

The milk was cooled from $\mathbf{35}$℃ to $\mathbf{34}$℃ , which means cooling tower is not effective in this case since it needs large area for the heat exchanger to obtain this reduction.

Case study two: Al-Safa Dairy factory

The development of technology leads to high growth in industry in several areas, such as dairy industry which is important all over the world because the number of consumers for its products increases continuously.

Whey, obtained as a by-product in cheese and labaneh industry, is the watery portion or serum that remains after coagulation that separates from the curd during cheese making. It is a dilute liquid containing lactose, protein, minerals, and traces of fat. It contains approximately 6% total solids, of which 70% or more is lactose and about 0.7% is whey proteins.

Presently about 50% of whey produced is utilized as a food product for either human or animal consumption. This number has held steady during a period in which the production of cheese (and also the amount of whey generated) has grown at a significant rate. (ZEHR, 1997)

In its dilute form, whey has little or no market value. Thus, the use of whey as a food product requires processing of some type. In general, the whey is first concentrated either by evaporation or by a filtration system. It can then be kept concentrated or dried to a powder either with a spray drying system or a roller drying system. Each of these processing steps is highly energy intensive.

Whey issue in Palestine

In Palestine, most factories produce large amounts of whey, which are disposed in to waste water without utilization, while a very small amount of this whey is used as additives in other products such as flavored milk products.

The white cheese and Labaneh are considered the main sources for whey production. It is estimated that (82-84) % of milk used in white cheese production ends up as whey, while in Labaneh this fraction is (60-63) %. (Khalad Al-Khalele et. al.)

The Dairy industry sector is one of the fastest-growing sectors and plays a major role in the Palestinian economy. Large amounts of the raw milk are used in this industry, many farmers sell the milk to the dairy factories, and many workers are employed in this sector.

For this reason, the dairy industry is considered as improvement of economy.

There are many dairy factories in Palestine, like:

1. Al-Safa in Nablus
2. AL – Binar in Ramallah
3. AL-Gibreeni in Hebron
4. AL-Junidi in Hebron
5. Al-Qaysi in Tulkarm

Whey processing by evaporation

The liquid whey byproduct has market value only if it is concentrated or powdered. For the purpose of concentration whey, the cheese industry uses falling-film type evaporation systems due to the temperature sensitivity of the product. The condensed whey processing is highly energy intensive due to the heating required.

Evaporation is the removal of solvent as vapor from a solution. It is the operation which is used for concentration of solution. There could be single effect evaporators or multiple Effect evaporators.

Multiple effect evaporator control is a problem that has been widely reported in the food industries. Therefore, evaporation is a very important unit operation and must be controlled smoothly. Process optimization has always been a noble objective of engineers entrusted with the responsibility for process development and improvement throughout the food industry.

The thermodynamic principle of the multi-effect evaporator consists of a series of reboilers; the vapor leaves one stage is condensed and used as the heat source for another stage.

In this report, the evaporation process is used in whey treatment to increase its solid content from (6.5-26) %. The concentrated whey is then treated to produce useful final products as supplements, and drinking yogurt.

The data were collected from a previous study "**Recovery and Reuse of Waste Whey in Palestine Dairy Industry**"(Khalad Al-Khalele et. al.), which talked about whey treatment for Al-Safa factory.

At Al-Safa factory, the amount of entered milk equals (11000 – 12000) L/day, it divides as follow in table (13)

Table 13: Percentage of original milk used for different products

Type of dairy product	Percentage of origin milk
Yogurt	20%
White Cheese	15%
Labaneh	25%
UHT milk , chocco and banana flavored taste	40%

The whey produced from cheese is about 1400 (L/day) and from labaneh about $3500(L/day)$ (Khalad Al-Khalele et. al.)

Theory and equations

This section includes all the adopted equations to perform different calculations in several cases, to facilitate understanding of the equations, this section was divided according to the effects follows:

1. **Single stage evaporator**

This type of evaporators has limited industrial applications, the understanding of this process is essential and would facilitate understanding of these systems, which are more complex.

Single stage evaporator scheme is shown in figure (17) below:

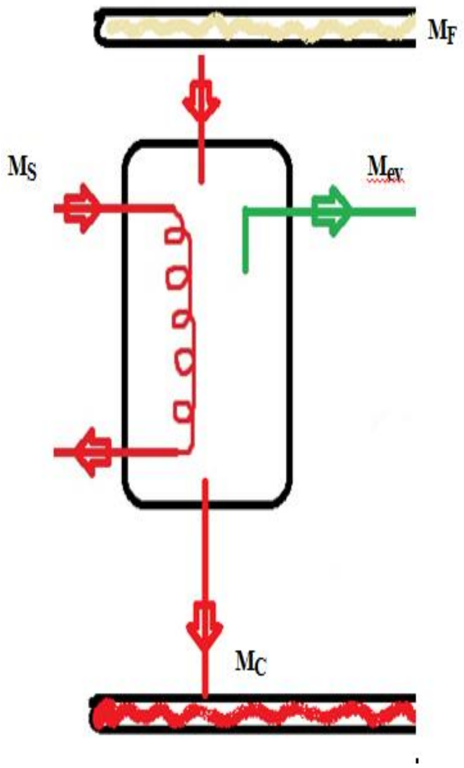

Figure 17: Schematic of a single stage evaporator

The equations of the evaporators are crossed, the mass and energy balance equations are illustrated below:

$$M_f = M_{ev} + M_c$$

M_f: Mass flow rate of the feed whey

M_{ev}: Mass flow rate of the evaporated whey

M_c: Mass flow rate of the concentrated whey

$$M_f X_f = M_c X_c$$

X_f:The input feed whey concentration

X_c: The concentrated whey concentration

$$Q_e = M_f \times C_p \times \left(T_c - T_f\right) + M_v \lambda_v = M_s \lambda_s$$

Q_e: Thermal load of the evaporator (kW)

T_c: Temperature of the concentrated whey (°C)

T_f: Temperature of the feed whey (°C)

λ_v: Latent heat of the evaporated whey (kJ/kg)

M_s: Mass flow rate of steam consumption (kg/s)

λ_s: Latent heat of the steam (kJ/kg)

The required heat transfer surface area in the evaporator is obtained from: the amount of the heat to be transferred Qe, the overall heat transfer coefficient Ue, and the temperature difference between concentrated whey and Utility steam.

$$U_e = 1.9695 + (1.2057 \times 10^{-2} \times T_c) - \left(8.5989 \times 10^{-5} \times {T_c}^2\right) - (2.5651 \times 10^{-7} \times {T_c}^3)$$

U_e: The overall heat transfer coefficient of the evaporator

$$A_e = \frac{Q_e}{U_e \times (T_s - T_c)}$$

A_e: The evaporator area

T_s: Temperature of utility steam

2. Single stage evaporator with condenser

In addition to the above equations, this part includes additional equations related to the condenser. Figure (18) shows the single stage evaporator with condenser scheme:

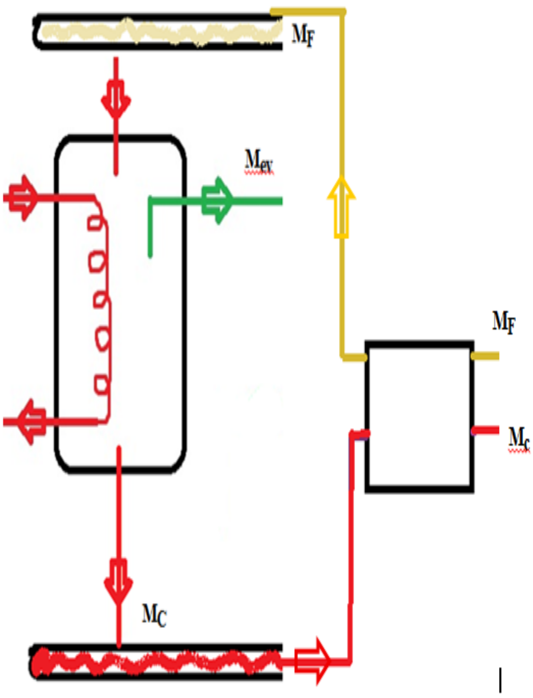

Figure 18: Schematic of single stage evaporator with condenser

The vapor condensation temperature and consequently the pressure in the vapor space for both the evaporator and the condenser is controlled by: the feed whey temperature T_f, the available heat transfer area in the condenser A_e, the overall heat transfer coefficient between the condensing vapor and the circulating whey U_e, These parameters are detailed in the equations below:

$$Q_c = M_f \times C_p \times \left(T_f - T_c\right) = M_{ev}\lambda_v$$

Q_c: Thermal load of the condenser

$$LMTD = \frac{T_{f,out} - T_{f,in}}{\ln(\frac{T_{ev} - T_{f,in}}{T_{ev} - T_{f,out}})}$$

$LMTD$: Log mean temperature difference

$T_{f,out}$: Temperature of the output feed stream from the condenser

$T_{f,in}$: Temperature of the input feed stream to the condenser

$U_c = 1.7194 + (3.2063 \times 10^{-3} \times Tv) + (1.597 \times 10^{-5} \times Tv^2) - (1.9918 \times 10^{-7} \times Tv^3)$

U_c: The overall heat transfer coefficient of the condenser

T_v: The vapor temperature

$$A_c = \frac{Q_c}{U_c \times LMTD}$$

3. 3-Stage evaporator

Multiple-effect evaporation is evaporation in multiple stages, whereby the vapors generated in one stage serve as heating ‘ steam ’ to the next stage. Thus, the first stage acts as a ‘steam generator’ for the second which acts as a condenser to the first and so on. The number of ‘effects’ is the number of stages thus arranged. The first effect is heated with boiler steam. A schematic of the 3-stage evaporator in the original case is shown in figure (19).

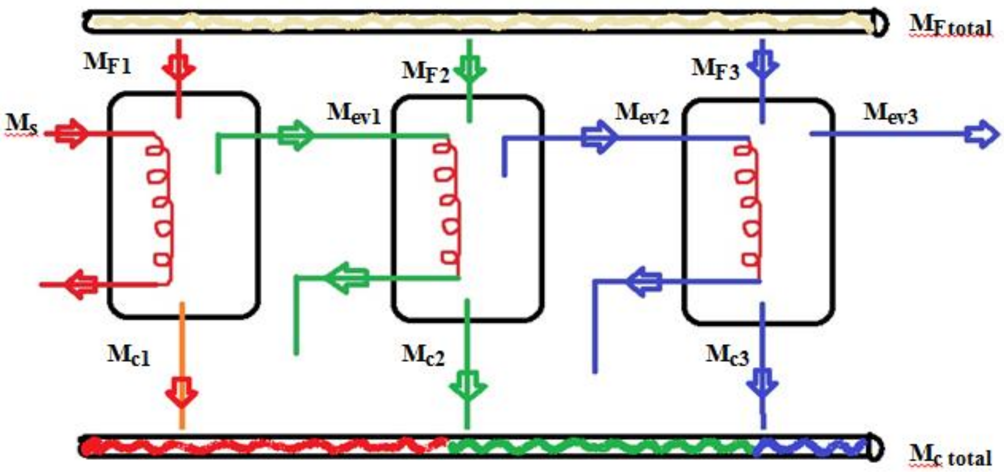

Figure 19: Schematic of 3- stage evaporator in the original case

The following questions are used to find concentrated flow rate Mc, evaporated flowrate Mev, and utility steam demand Ms of the first stage:

$$M_{c1} = M_{f1} - M_{ev1}$$

$$M_{ev1} = \frac{(M_s \times \lambda_{@100℃}) - (M_{f1} \times C_p \times \Delta T)}{\lambda_{@80℃}}$$

$$Ms = \frac{M_f \times C_p \times (T_c - T_f) + M_{ev}\lambda_v}{\lambda_{@100℃}}$$

The following questions are used to find concentrated flow rate Mc and evaporated flowrate M_{ev} of the second stage:

$$M_{c2} = M_{f2} - M_{ev2}$$

$$M_{ev2} = \frac{(M_{ev1} \times \lambda_{@80℃}) - \left(M_{f2} \times C_p \times \Delta T\right)}{\lambda_{@60℃}}$$

The following question is used to find concentrated flow rate Mc of the third stage:

$$M_{c3} = M_{f3} - M_{ev3}$$

This equation is to find the total mass flow rate of the feed whey from all stages.

$$M_{f,total} = M_{f1} + M_{f2} + M_{f3}$$

Energy Analysis for evaporation system

Significant opportunities for reduction of utility use have been identified for the evaporation system. Making use of the low temperature vapor rejected from the evaporation system by preheating the feed whey provides effective opportunity to reduce the utility demand and energy recovery. Pinch analysis has been applied in this case, to investigate heat recovery options through heat exchange units, by different scenarios explained in the next part.

Scenarios to reduce the utility requirement

Six major scenarios were considered as a trial to make the proper modification, all the proposed scenarios were clarified in the term of the amount of energy usage.

These scenarios graded from the original one (Single stage without reheating) to the three stages evaporator system as in figure (20) below:

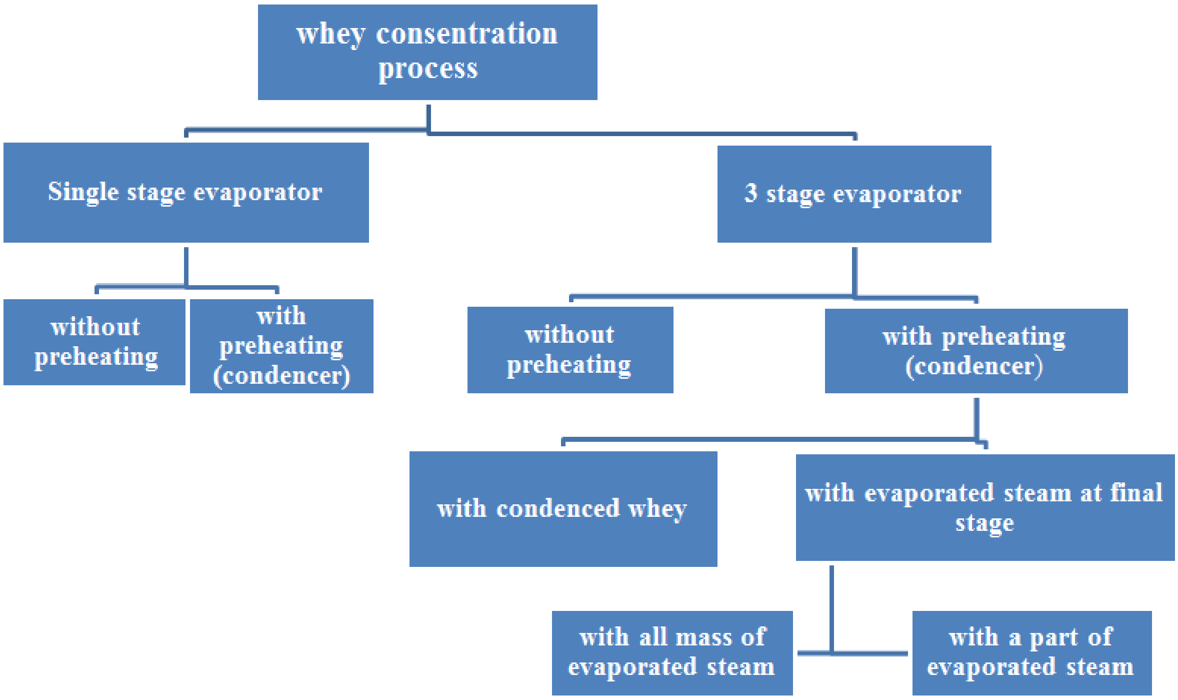

Figure 20: Several scenarios to reduce the utility requirement.

All of the proposed modification are based on the preheating process of the feed whey in order to reduce utility steam demand.

Scenario 1: Single stage without reheating (concentrated whey from 6.5% to 26%)

Single stage evaporator was designed to evaporate the feed whey as shown in figure (17). The main conducted results are listed in table (14) below:

Table 14: Main results conducted from scenario 1

M_f	0.0486
M_c	0.0123
M_{ev}	0.0363
Q_e	95
U_e	3.93
A_e	2.43

Scenario 2: Single stage with reheating (concentrated whey from 6.5% to 26%)

In this scenario, a single stage evaporator was modified by adding a condenser to preheat the feed whey by using the evaporated stream at 80°C before entering the single stage evaporator in order to reduce the boiler demand as shown in figure (18).

After comparing scenario 2 with the previous scenario, the evaporator demand has reduced from $95kW$ to $87.7\ kW$.

In this scenario, the evaporator demand will reduce as a result of reheating by condenser as follows:

$$Q_c = M_f \times C_p \times \left(T_f - T_c\right) = M_{ev}\lambda_v$$

$$= 0.0486 \times 4 \times (80 - 25) = 8.748\ kW$$

From the previous equation, Mev should be founded to satisfy the previous equation:

$$Q_c = M_{ev}\lambda_v \quad , \text{where } \lambda_{@80°C} = 2308kJ/kg$$

This leads to: $$8.748 = M_{ev} \times 2308$$

$$\therefore M_{ev,reheating} = 0.004\, kg/s$$

So, there is an amount oMf ev goes as waste:

$$M_{\ ev,waste} = 0.0364 - 0.004 = 0.0325\, kg/s$$

The main results conducted from this case are listed in table (15) below:

Table 15: Main results conducted from scenario 2

$M_f\ (kg/s)$	0.0486
M_c (kg/s)	0.0123
$M_{ev,total}$(kg/s)	0.0363
$M_{ev,reheating}$ (kg/s)	0.004
$M_{\ ev,waste}$(kg/s)	0.0325
$Q_c(kW)$	8.748
$U_c\ (kW/m^2.$℃)	1.976
$A_c(m^2)$	0.167
$Q_e(kW)$	87.7
$U_e\ (kW/m^2.$℃)	3.93
$A_e(m^2)$	2.2

According to the results obtained from scenario1 and scenario 2, it's observed that the utility requirement still high. As a result, a three stage evaporator was proposed in the following four scenarios with different effective modifications to make further savings.

Scenario 3: 3-Stage evaporator without reheating (concentered feed whey at 25℃, from 6.5% to 24%)

In this Scenario, a 3-stage evaporator was studied in a simple configuration without any reheating process as shown in figure (19). Several iterations were performed to find the optimum concentration value of whey as follows in table (16)

Table 16: Main results conducted from scenario 3

Iteration	fr_1	fr_2	fr_3	X_{c1}	X_{c2}	X_{c3}	$X_{c,avg.}$
1	0.2	0.3	0.5	0.53	0.129	0.09	0.12
2	0.3	0.3	0.4	0.7	0.345	0.15	0.25
3	0.3	0.35	0.35	0.4	0.174	0.152	0.197
4	0.3	0.35	0.35	0.5	0.189	0.162	0.216
5	0.3	0.3	0.4	0.5	0.289	0.1378	0.2202
6	0.35	0.4	0.25	0.3	0.16	0.594	0.245
7	0.4	0.3	0.3	0.18	0.268	0.2172	0.212

As shown in the previous table, the optimum value with the best energy recovery was at iteration 6 with $X = 24\%$

Scenario 4: 3-Stage evaporator with preheating of feed whey from 25℃ to 34℃ by using concentrated whey streams at average temperature 60℃.

The concentrated whey streams out from scenario 3 can be used as an effective choice to preheat the feed as shown in figure (21).

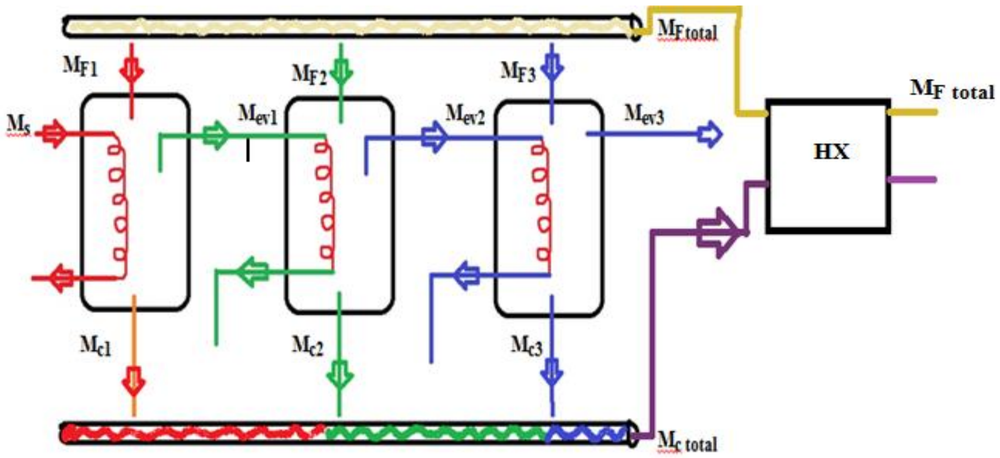

Figure 21: Schematic of 3- stage evaporator with preheating modification by using concentrated stream

Table (17) below illustrated the mass flow rate and temperature of the concentrated whey streams out from the 3-stage evaporator without reheating as follow:

Table 17: Temperature and flowrates of concentrated whey in the original case

stage	Temperature(℃)	Concentrated flow rate (Kg/s)
1	90	0.0019
2	70	0.00328
3	50	0.00917

The following equation was used to find the average temperature of the total concentrated whey enters the preheater:

$$\frac{\left(m_{c1} \times C_p \times T_1\right) + \left(m_{c2} \times C_p \times T_2\right) + \left(m_{c3} \times C_p \times T_3\right)}{m_{c,total} \times C_p} = 60℃$$

$$m_{c,total} = m_{c1} + m_{c2} + m_{c3} = 0.0143(Kg/s)$$

The total concentrated stream could preheat the feed stream to 34℃ based on the energy balance equation as follows:

$$\dot{m}_{brine} \times C_{p,brine} \times \Delta T_{brine} = \dot{m}_{whey} \times C_{p,whey} \times \Delta T_{whey}$$

$$0.01435 \times (60 - 30) = 0.0486 \times (X - 25)$$

$$8.86 = X - 25$$

$$X = 34℃$$

Different iterations were conducted to find the optimum concentration value of whey at input temperature of 34℃ as following in table (18)

Table 18: Main results conducted from scenario 4

iteration	fr_1	fr_2	fr_3	X_{c1}	X_{c2}	X_{c3}	$X_{c,avg.}$
1	0.5	0.3	0.2	0.1	0.1326	0.235	0.123
2	0.3	0.3	0.4	0.5	0.31	0.146	0.232
3	0.3	0.35	0.35	0.5	0.196	0.175	0.23
4	0.3	0.35	0.35	0.4	0.181	0.163	0.21
5	0.4	0.3	0.3	0.18	0.29	0.24	0.22

Scenario 5: 3-Stage evaporator with reheating of feed whey by the vapor at 40 C

In this case, the evaporated whey from the last stage at 40℃ is used to preheat the feed by make it condensed at constant temperature (40℃) as illustrated in figure (22).

Figure 22: Heat recovry between the vapor stream at 40℃ and feed stream at 25℃

The result was obtained as following:

$$M_v \lambda_v = \dot{m} \times C_p \times (T_{f,out} - T_{f,in})$$

After calculations, it was clear that $Q_{available} \gg Q_{needed}$, which means condensation can`t happen, and so this proposed scenario is not feasible.

Scenario 6: 3-Stage evaporator with reheating of feed whey by the vapor at 40℃ from 25℃ to 40℃

It is proposed to rise the feed whey stream to 40℃ by using $(0.001212)\ kg\ /s$ from the evaporated stream, about $0.0091\ kg/s$ of it is waste can be used in other applications as shown in figure (23) below:

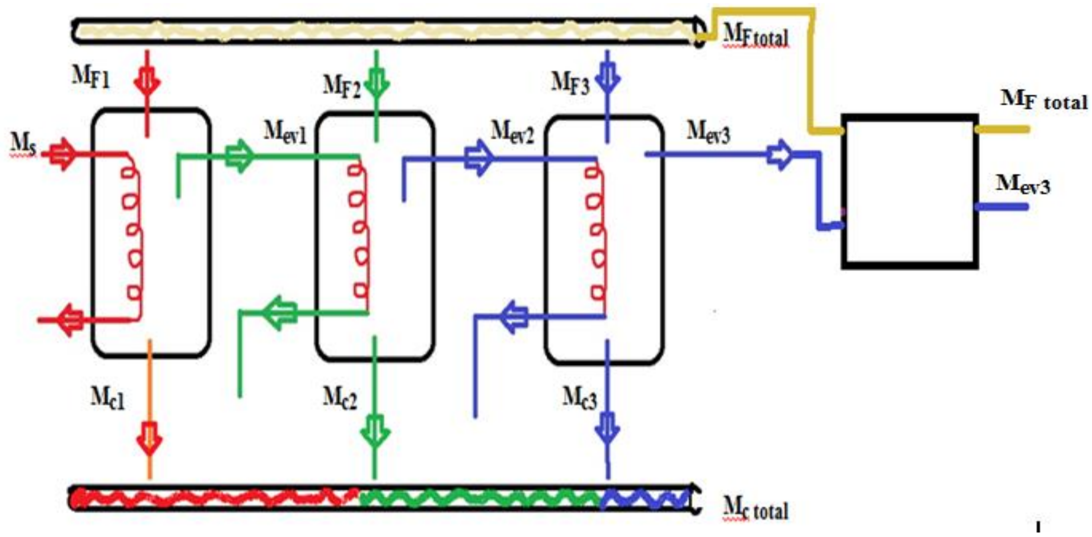

Figure 23: Schematic of 3- stage evaporator with preheating modification by condensation vapor stream at 40℃

Table 19 illustrates this case with diffirenet iterations to find optimum concentarion value of whey

Table 19: Main results conducted from scenario 6

Iteration	fr_1	fr_2	fr_3	X_{c1}	X_{c2}	X_{c3}	$X_{c,avg.}$
1	0.5	0.3	0.2	0.1	0.135	0.26	0.12515
2	0.3	0.3	0.4	0.5	0.33	0.152	0.2407
3	0.3	0.35	0.35	0.5	0.203	0.185	0.23701
4	0.3	0.35	0.35	0.4	0.187	0.172	0.21459
5	0.4	0.3	0.3	0.18	0.299	0.2607	0.22857

As shown in the above table, the optimum value was iteration 2 with $X = 24\%$

Economical evaluation

The various cost items can be expressed in terms of the system-operating variables and parameters as follows**:**

Annualized Cost of Steam

The cost of steam consumption can be estimated according to following equations:

$$Q_{s,out} = M_s \times C_p \times \Delta T$$

$$Q_{in} = \frac{Q_{s,out}}{\eta_{boiler}}$$

$$Energy(kWh) = Q_{in} \times working\ hours\ (\frac{hr}{year})$$

$$Energy\ (MJ) = Energy(kWh) \times 3.6(\frac{MJ}{kWh})$$

$$Kilograms\ of\ Disel = \frac{Energy\ (MJ)}{Heat\ content\ of\ disel\ \left(\frac{MJ}{kg}\right)}$$

$$Liters\ of\ Disel = \frac{Kilograms\ of\ Disel\ (kg)}{Density\ of\ disel\ (\frac{kg}{m^3})}$$

$$Cost = Liters\ of\ Disel\ (L) \times cost\ of\ Liter\ of\ Disel\ (\frac{NIS}{L})$$

The steam consumption can be represented according to the following equations:

1. **Single stage evaporator :**

$$M_s = \frac{M_f \times C_p \times \left(T_c - T_f\right) + M_{ev}\lambda_v}{\lambda_{s@100℃}}$$

Where,

M_s: Mass flow rate of steam consumption $(\frac{kg}{s})$

λ: Latent heat of vaporization, $(\frac{kJ}{kg})$

M_f : Flow rate of feed solution $(\frac{kg}{second})$

For a single stage with condenser, the mass of steam utility was reduced as a result of preheating process by condenser. And the mass of steam was calculated as the previous equation.

2. **3- stage evaporator**

The mass of steam consumed by the evaporator was calculated using the equation below:

$$M_s = \frac{M_f \times C_p \times \left(T_c - T_f\right) + M_{ev}\lambda_v}{\lambda_{s@100℃}}$$

Annualized capital cost:

The following equation is used to estimate the capital cost of the falling film evaporator and the condenser:

$$Capital\ cost\ (\$) = 10000 \times A^{0.52} \text{ (Sinnott, 2005)}$$

A: $evaporator\ or\ condensor\ area$

To convert the capital cost (\$) to annualized cost ($\$/year$), the capital price was multiplied by a conversion factor of 0.11017, and to convert from dollar to NIS, the answer was multiplied by $3.7 NIS/\$$

Total annualized cost:

$$Total\ cost\left(\frac{NIS}{year}\right) = \text{ annualized cost of steam}\left(\frac{NIS}{year}\right) + \text{annualized capital cost }\left(\frac{NIS}{year}\right)$$

Simple Pay Back Period (SPBP):

SPBP is a good indicator to check the feasibility of a project, it`s usually ranging from $4-6$ years in such projects, it’s calculated using the following equation:

$$SPBP(year) = \frac{Total\ investment\ (NIS)}{Total\ savings\ \left(\frac{NIS}{year}\right)}$$

Results

This section shows the cost of each stage, where these costs have been divided into Energy, capital, and total costs as mentioned before.

Single stage evaporator:

Scenario1 and scenario 2 of the single stage evaporation process were economically evaluated based on the mass flow rate of the utility steam required to concentrate the feed whey, so the heat amount and the evaporator area can be determined .Table (20) clarifies costs resulted from that process.

<table>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Effect Area</th><th rowspan="2">Ms. utility</th><th rowspan="2">Qs</th><th rowspan="2">Q</th><th colspan="3">Annualized Cost (NIS/year)</th><th rowspan="2">Liter Cost (NIS/L)</th></tr>
<tr><th>Energy</th><th>Capital</th><th>Total</th></tr>
<tr><td rowspan="2">1</td><td colspan="8">Evaporator only</td></tr>
<tr><td>2.43</td><td>0.042</td><td>12.6</td><td>95</td><td>19536</td><td>8850</td><td>28386</td><td>0.26</td></tr>
<tr><td rowspan="5">2</td><td colspan="8">Evaporator</td></tr>
<tr><td>2.2</td><td>0.039</td><td>12</td><td>87.7</td><td>18635</td><td>6142</td><td>24777</td><td></td></tr>
<tr><td colspan="8">Condenser</td></tr>
<tr><td>0.167</td><td>-</td><td>8.7</td><td>8.75</td><td>-</td><td>1607</td><td>1607</td><td></td></tr>
<tr><td colspan="5">Total cost of scenario 2</td><td>7749</td><td></td><td>26384</td></tr>
</table>

As it’s clear from the above table, the mass of required steam was decreased by 7% when using single stage evaporator with condenser to preheat the feed whey, which leads to reduction of 5% in energy cost, while the capital cost increased by 20%.

Also the results showed that production cost in the scenario 2 was lower than it in scenario 1, and this is because the preheater existence in scenario 2.

Multiple effect evaporator:

For the multi effect evaporation process, the economical calculation was a bit different. There are three areas of evaporators lead to three capital costs for each stage, summed in capital cost column as shown in table (21).

Table 20: Multiple effect evaporator costs

Scenario	Xc,avg.	Effect Area	Ms. utility	Qs	Qe	Annulized Cost (NIS/year)			Liter Cost (NIS/L)
						Energy	Capital	Total	
3	24%	1.6205 0.4893 0.2792	0.0156	4.68	35.184 33.823 32.461	7267.77	10150	17418	0.135
4	23%	1.4992 0.454 0.25989	0.01443	4.524	32.549 31.382 30.216	7025.2	9758	16783	0.137
6	24.0%	1.483 0.4489 0.25688	0.01427	4.474	32.199 31.033 23.866	6947.31	9702	16647	0.141

The table above shows the expected results of mass flow rates needed in the evaporation process and energy costs. A reduction of 63% in each of the mass flow rate, and energy costs, which considered a valuable decreasing. But the capital cost was increased as a normal result of three effect evaporator appearance.

Moving to scenario 4, and scenario 6; the reduction in steam flow rate and energy cost is not effective, the reduction percentage of them was 7% and 3% respectively. While the reduction in the capital cost was 0.014%.

In addition, the results showed that production cost in the scenario 3 was lower than it in scenarios 4 and 6.

CHAPTER 7: CONCLUSION

Pinch Point Analysis is a systematic process design methodology consisting of number of concepts and techniques that ensure an optimal use of energy.

This project focused on the identification of actions related to pinch analysis to reduce the energy cost in two food factories located in Nablus city, Al-Arz ice cream factory and Al-Safa dairy factory.

After preforming thermal and economical analysis with seven modifications based on changing of ΔT_{min} value in Al-Arz proposed case, it`s observed that the annual energy cost was the main factor to determine the total annual cost.

The HEN optimization is highly recommended in Al Arz case, since it has total savings between $310816(NIS/year) - 391991\ (NIS/year)$

As for Al-Safa proposed case, the maximum annualized total cost in evaporation process was obtained from the single stage evaporator with $28386 NIS/year$, while the minimum annualized total cost was obtained from the 3-Stage evaporator with $16649 NIS/year$.

From this proposed case, it can be concluded that 3-Stage evaporation system was more effective than Single stage evaporation system. The production cost in the 3-stage evaporation was 0.135 NIS/L while it was 0.26 NIS/L in the single.

CHAPTER 8: RECOMMENDATIONS

The following recommendations are offered for related researches in the field of heat recovery and pinch analysis:

1. Perform such studies at different processes in different industries.
2. Perform studies to recover heat in dairy processes in details.
3. Study the possibility for the concentrated whey to be dried and sold and powder.
4. Study the optimization for the number of effects of multiple stage evaporator.
5. Perform studies for the water pinch or water recovery disposed from whey processing.
6. Adopt updated cost index in different calculations to obtain more accurate economical results.

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