CZECH TECHNICAL UNIVERSITY
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FACULTY OF MECHANICAL ENGINEERING

Department of Process Engineering

Master Thesis

Energy analysis of milk powder production line

2019 Sumit Upadhyay

MASTER'S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Upadhyay Sumit** Personal ID number: **473394**
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II. Master's thesis details

Master's thesis title in English:

Energy analysis of milk powder production line

Master's thesis title in Czech:

Energetická analýza výrobní linky sušeného mléka

Guidelines:

Prepare literature review focused on the issues of milk powder production, used equipment, procedures and its energetic efficiency improvement.
Analyze the current state of the milk powder processing line (including PFD scheme, balances and its energy efficiency) and develop the modification of the processing line leading to the improvement of the energy efficiency of the production line (in form of techno-economical study).

Bibliography / sources:

According to the recommendation of the supervisor.

Name and workplace of master's thesis supervisor:

Ing. Jaromír Štancl, Ph.D., Department of Process Engineering, FME

Name and workplace of second master's thesis supervisor or consultant:

Date of master's thesis assignment: **23.04.2019** Deadline for master's thesis submission: **07.06.2019**

Assignment valid until: ______

Ing. Jaromír Štancl, Ph.D. Supervisor's signature	prof. Ing. Tomáš Jirout, Ph.D. Head of department's signature	prof. Ing. Michael Valášek, DrSc. Dean's signature

III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

30-04-2019
Date of assignment receipt

Student's signature

Annotation sheet

Name: Sumit

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Title Czech: Energetická analýza výrobní linky sušeného mléka

Title English: Energy analysis of milk powder production line

Scope of work: number of pages: 51

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Supervisor: Ing. Jaromir Štancl Ph.D.

Submitter: Czech Technical University in Prague, Faculty of Mechanical Engineering, Department of Process Engineering

Annotation - Czech: Připravit přehled literatury zaměřený na problematiku výroby sušeného mléka, použitého zařízení, postupů a jeho energetické zvýšení účinnosti. Analýza současného stavu linky na zpracování sušeného mléka (včetně schématu PFD, rovnováhy a jeho energetické účinnosti) a vyvinout úpravu výrobní linky vedoucí ke zlepšení energetické účinnosti výroby linka (ve formě techno-ekonomické studie).

Annotation - English: Prepare literature review focused on the issues of milk powder production, used equipment, procedures and its energetic efficiency improvement. Analyze the current state of the milk powder processing line (including PFD scheme, balances and its energy efficiency) and develop the modification of the processing line leading to the improvement of the energy efficiency of the production line (in form of techno-economical study).

Keywords: Exergy, Six sigma, Efficiency, PFD, Strategy, Improvement, Production

Utilization: For Department of Process Engineering, Czech Technical University in Prague

Declaration

Supervisor: Ing. Jaromir Štancl Ph.D.

I declare that I have produced the submitted work independently and that I have provided all the information sources used in accordance with the Methodological Guideline on Ethical Principles in the Preparation of Graduate Final Theses.

In Prague on ....   ……………

Sumit Upadhyay

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I wish to express my sincerest gratitude to my advisors, Ing. Jaromir Štancl Ph.D. for their inciting and skillful guidance throughout this work.

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Preface

This thesis work is a case study on local dairy industry called Company A dairy located in České Budějovice, a city of Czech Republic. The entire work is divided into seven chapters.

The first chapter introduces the thesis to the readers in terms of motivation behind the project, followed by a brief background of the dairy with which the collaboration of this project has been carried out. The second chapter gives a brief literature review of exergy analysis and its dependence on temperature. It also gives a detailed description of the methodology followed in the present work to perform the exergy study of the milk dairy. A brief description of milk powder production process along with its energy efficiency studies is presented in the third chapter. The fourth chapter provides a detailed picture of the modeling and simulation of the milk powder plant followed by its exergy analysis. In the analysis, different sections of the plant are located which showed comparatively below par energy efficiencies. Thus, to improve this aspect of the plant, a few strategies are devised and discussed in the last part of this section in order to make the overall plant more energy efficient. Chapter five include six sigma methodology with the help of which we can improve the quality and also optimize the efficiency of plant. Chapter six state the reason why we cannot fulfil economic study for this work. The final chapter summarizes the entire thesis work and provides suggestion on future scopes of the project.

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Nomenclature

Roman Alphabet

Symbol	*Description*	*Units*
C_p	Specific heat capacity at constant pressure	kJ kg^{-1} K^{-1}
e_x	Specific exergy	kJ kg^{-1}
H	Specific enthalpy	kJ kg^{-1}
$\dot{m}$	Mass flow rate	kg s^{-1}
P	Pressure of a system	kg m^{-1} s^{-2}
$\dot{Q}$	Heat flow rate	kJ s^{-1}
R	universal gas constant (= 8.314)	kJ kg^{-1} K^{-1}
s	Specific entropy	kJ kg^{-1} K^{-1}
T	Time	s
T	Temperature of a system	K
$\dot{W}$	Power (or work per unit time)	kJ s^{-1}

Greek Alphabet

Symbol	*Description*	*Units*
Δ	Change in property	–
H	Exergy efficiency	–

Subscripts

Symbol	*Description*
0	Thermodynamic state with ambient conditions
1	Thermodynamic state
2	Thermodynamic state
A	Fluid

B	Fluid
C_v	Control volume
Ex	Exergy
I	Initial
in	Inlet stream
f	Final
out	Outlet stream
p	Constant pressure
vap	Vaporization

Superscripts

Symbol	*Description*
P	Pressure
T	Temperature

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Chapter 1. Introduction

Consumption of fossil fuels results in the emission of greenhouse gases which can be significantly reduced by making the industrial sector more energy efficient [1]. Several scientific and engineering methods are being continuously developed for the identification of potential energy saving strategies for the large-scale industries. One such method is the basic energy analysis, the conventional approach to study various energy consumption processes [7]. However, the energy analysis is unable to distinguish the different qualities of energy such as heat quality which is dependent on the heat source temperature [8]. Due to these shortcomings of energy analysis, the exergy analysis which provides a much clearer picture of the process flow has proved to be a better tool to solve the purpose.

Czech Republic is now one of the largest producers of milk [3] Which is useful to vegetarian population around Europe and thus it is the largest consumer of its own dairy products such as butter, cheese, milk powder etc. as these are the only acceptable sources of animal protein for the vegetarians [5]. Substantial amounts of fresh water and energy are consumed during milk processing which in turns affects the sustainability of the plant. Thus, the motivation behind this work was to study the energy efficiency at Czech's largest milk processing plant followed by proposing retrofits to improve the plant's sustainability. So we can optimize the plant by exergy analysis and six sigma methodology.

In our work, we have made a case study on the Company A Dairy, located in Ceske Budejovice , Czech Republic, as Company A is considered one of the largest food brand in Czech republic with unparalleled production of milk and milk products over the past many years. It works on the basis of collection of milk from around villagers [5].

Chapter 2. Exergy analysis

2.1 Literature review

Energy can be broadly classified into: (1) High grade and (2) Low grade energy. **High grade** form of energy is defines as the form of energy which can easily convert to other forms of energy (W → W, such as electrical energy → thermal energy in electrical heater) is not dictated by the second law of thermodynamics. 100% conversion of high-grade energy to low grade energy is possible but reverse is not possible, although it is undesirable, keeps taking place in our environment. This is due to dissipation of heat because of friction (for an instance mechanical work converts into electricity, but some losses happen because of the friction in the bearing of machinery). Thus, both the first and second law of thermodynamics are to be considered for analysis. **Low grade** energy is defines as the form of energy which is difficult to convert to other forms of energy such as heat due to combustion, fission, fusion reactions as well as internal energies are highly random in nature and their conversion to high grade form (Q → W) has been more of interest. But the second law of thermodynamics dictates that complete conversion of low-grade energy (Q) to high grade energy (W) is never possible. Therefore, the portion of low-grade energy which is ready for change is called as available energy, or exergy and the part which gets rejected is known as unavailable energy or irreversibility [13]. Thus, the exergy analysis provides extensive and more profound penetration into the process and hence, is applicable for evaluation of process and optimization objectives [14]. Not only does it help to determine the type, location and magnitude of energy losses in a system, but by enabling the engineers to recognize the individual components efficiency it also helps to find ways to reduce these losses in order to make the system more energy efficient [14-15].

The term Exergy is a technical word use in engineering was first coined by Rant [33] in 1956, by using Greek word's ex and ergon that mean from work. Polish Professor Jan Szargut [34] explained exergy as: "Exergy is the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of its surrounding nature by means of reversible processes, involving interaction only with the above-mentioned components of nature”. After all the term reversible processes is mentioned , in different words, the exergy of a system at a certain thermodynamic state can be defined as maximum work potential that is the greatest quantity of work that can be accomplished when the system moves from that special state to a state of equilibrium with the surroundings.

In Thermodynamics with respect to Carnot engine exergy can be defined as

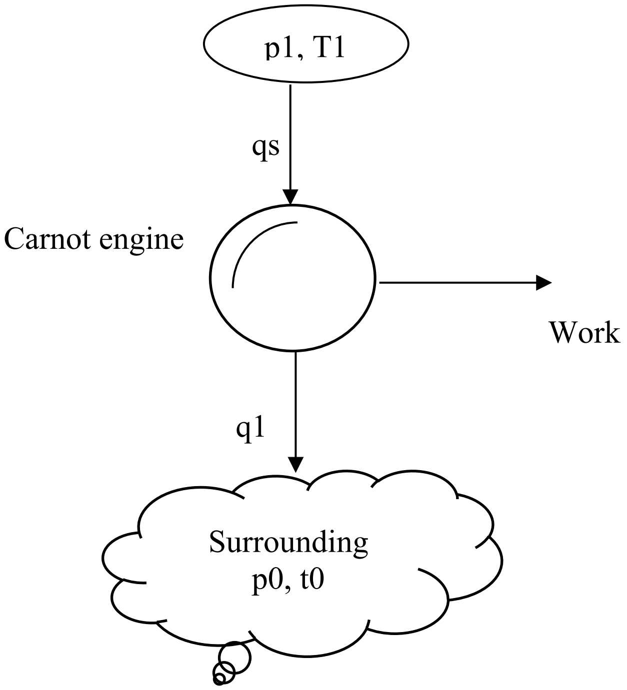


Figure 2. Carnot engine exergy

We use Carnot engine because Carnot efficiency is the maximum efficiency that can be achieved by the 2nd law of Thermodynamics.

Efficiency of Carnot engine can be given by the equation:-

$$\eta = \left(1 - \frac{t0}{t1}\right) \qquad (1)$$

Now efficiency can also be defined in general as the ration between work obtain and heat given, so we can rewrite equation 1 as,

$$\eta = \left(1 - \frac{t0}{t1}\right) = \frac{\text{work obtain}}{\text{Heat given}} \qquad (2)$$

$$\left(1 - \frac{t0}{t1}\right) = \frac{W_{max}}{Q} \qquad (3)$$

$$Q\left(1 - \frac{t0}{t1}\right) = W_{max} \qquad (4)$$

So, from equation 4 we get maximum work W_{max} that is the exergy.

2.2 Exergy dependence on temperature

Now, in this section we will learn how exergy depend on temperature. For that let us consider two system S1 and S2 at temperature T1 and T2 respectively and T1 is greater that T2. Now we need to know in which system exergy will be more [47].

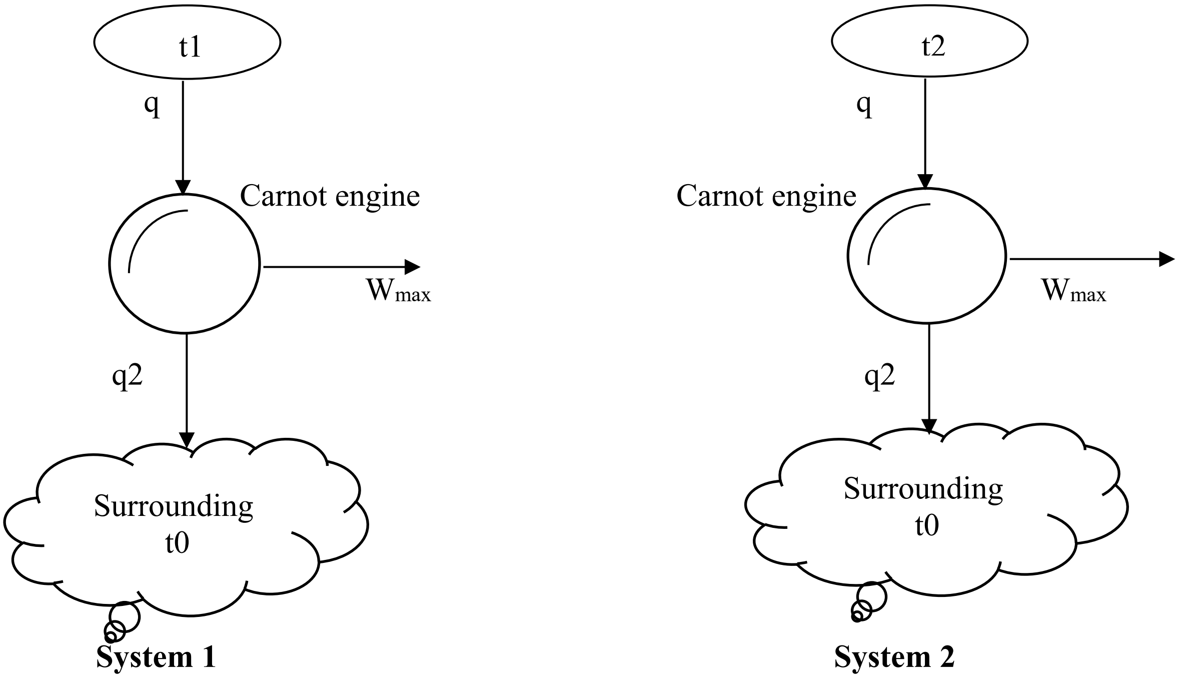


Figure 2 Carnot engine exergy comparison between different temperature

We know that Exergy is the maximum work which can be defined by equation 4 i.e. $q\left(1-\frac{t0}{t1}\right)=W_{max}$. Maximum work for system 1 and system 2 can be defined as

$q\left(1-\frac{t0}{t1}\right)=\boldsymbol{System\ 1}$ $q\left(1-\frac{t0}{t2}\right)=\boldsymbol{System\ 2}$

Suppose the values for t0 = 100 K, t1 = 300K, t2 = 200K. now put there given values in system 1 and system 2.

$q\left(1-\frac{100}{300}\right)=\boldsymbol{System\ 1}$ $q\left(1-\frac{100}{200}\right)=\boldsymbol{System\ 2}$

0.67q = system 1 = 67% 0.5q = system 2 = 50%

So from above calculation we get to know that system 1 has more potential then system 2, so mathematically we found that system has higher temperature has higher exergy considering surrounding temperature same.

Now energy, exergy, and their influence on the environment are strictly related as shown in Figure 3. For example, we all know that the stage of emissions on the environment is a severe concern for the community and it can be overcome by promoting scopes for resource utilization. However, this has sustainability relationships as even though it increases the lifetime of surviving resource reserves, but it is generally characterized by greater use of materials, manual labor, and more complicated devices. It was then found that the stage of energy resource utilization on the environment and achieving more satisfying resource-utilization efficiency can be best approached by taking exergy into the picture. Apart from that, as these topics are important factors in managing sustainable development, exergy also proved to be a crucial tool to provide the support for developing extensive methodologies for sustainability (shown in Figure 4). This was the focal spot of Paudel et al. in their work [15] where they examined the traditional production of canned mushrooms onward with three alternative Schemes via pinch and exergy analysis. The conventional production process included multiple processing steps for an instance, vacuum hydration, blanching, sterilization, etc. that are intense in energy and water usage. The product yield, utility usage, exergy waste, and water usage were used as sustainability signs. Their conclusions showed that while rearrangement of the production process could maximally save up to 27 % of the heat input and up to 26 % of the water usage, the most important improvement was achieved by reusing blanch water which increased the overall yield of the preservation and canning process by 10 %, also conserving water and exergy use in the production thereby making the process way more sustainable than what it used to be.

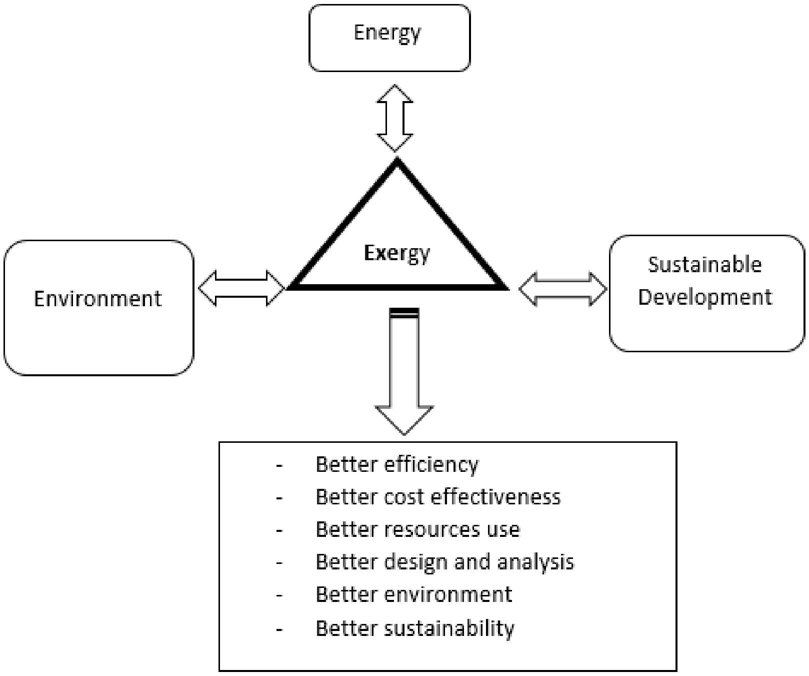


Figure 3. The integrative triangle which explains exergy [48].

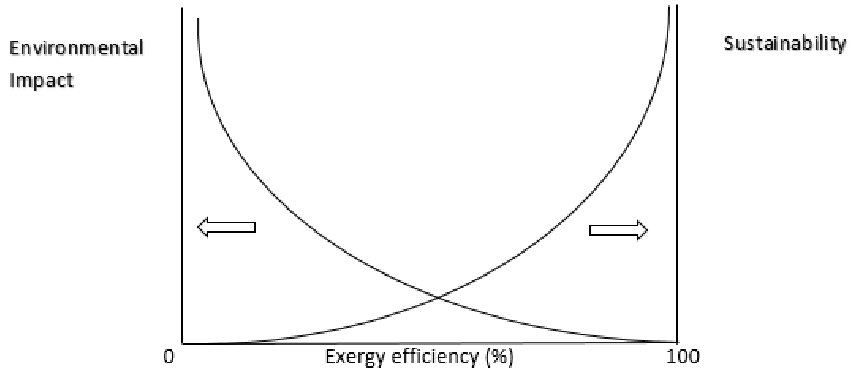


Figure 4. Qualitative representation of the relationship among the environmental influence and sustainability of a process, and its exergy performance [49]

2.3 Methodology

In this section, the balance of energy and on the basis of that appropriate exergy analysis is discussed, first by taking a generic reversible device undergoing thermo-mechanical processes, followed by replacing the device with the different type of equipment which were studied in our work.

A process of stream with temperature T_1 and pressure P_1 with slim amount of kinetic and potential energy, going through reversible physical processes as shown in Figure 5.

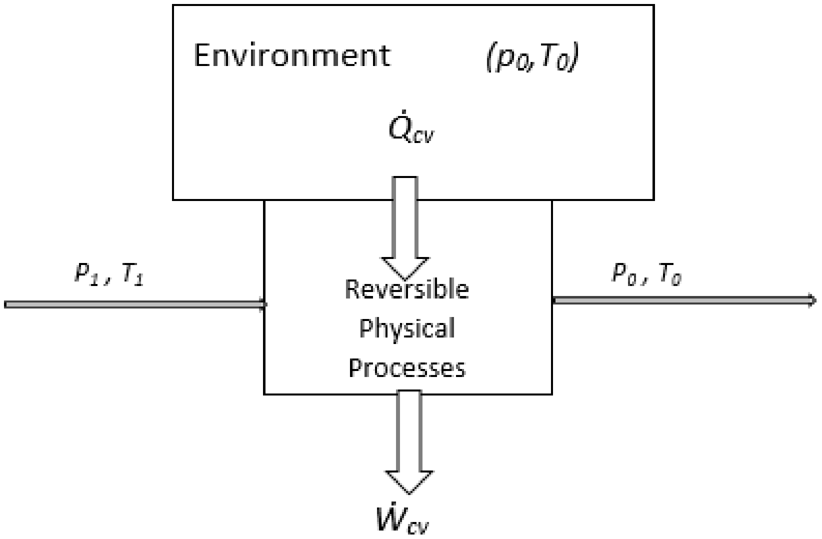


Figure 5. Reversible equipment (module) for managing thermo-mechanical [35]

With reference to Figure 5, it can be said that during heat exchange between the module and the surroundings (or environment) which is at state P_0, T_0 , maximum possible work is produced when the process stream at a state P_1, T_1 is brought to equilibrium with the environment, provided all processes are reversible in nature. An Energy balance for such a system output [35]:

$$\frac{dE_{cv}}{dt} = 0 = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}(h_1 - h_2) \tag{1}$$

Similarly, the entropy balance allowing no irreversibility output [35]:

$$\frac{dS_{cv}}{dt} = 0 = \frac{\dot{Q}_{cv}}{T_0} + \dot{m}(s_1 - s_2) \tag{2}$$

Equation (2) can be replaced to get an explanation for specific heat transfer [35]

$$\frac{\dot{Q}_{cv}}{\dot{m}} = T_0\left(s_0 - s_1\right) \tag{3}$$

Equation (1) can also be explained with respect to specific work and replaced to give [35]

$$\frac{\dot{W}_{cv}}{\dot{m}} = T_0(s_0 - s_1) - (h_0 - h_1) \tag{4}$$

The specific exergy of the process stream enrolling the ideal device in Figure 5 can be obtained from Equation (4) as follows [35]:

$$e_{x,1} = T_0(s_0 - s_1) - (h_0 - h_1) = (h_1 - h_0) - T_0(s_1 - s_0) \tag{5}$$

The difference in specific exergy when a system encounters a process from thermodynamic state 1 to a thermodynamic state 2 is then given by the expression (the enthalpy and entropy functions at the enclosing conditions (h0,s0) remove due to subtraction) [35]

$$\Delta e_x = (e_{x,2} - e_{x,1}) = (h_2 - h_1) - T_0(s_2 - s_1) = \Delta\mathrm{h} - T_0\Delta\mathrm{s} \tag{6}$$

This change in specific exergy, if negative, accounts to irreversibility, I.

Now as presented earlier, exergy losses take place in two ways: Internal losses occurring from process irreversibilities and external losses occurring from inappropriate utilization of exergy content in effluent streams and which finally goes to waste. But the overall exergy efficiency would only take into attention the internal losses those occur in the process. Thus, exergy efficiency is usually described as a ratio of useful exergy obtained from the process to total exergy input to the process and therefore, it is given by:

$$\boldsymbol{\eta_{e_x}} = {(\sum \boldsymbol{e_x})_{\boldsymbol{out}}} \Big/ {(\sum \boldsymbol{e_x})_{\boldsymbol{in}}} \tag{7}$$

where the subscript *out* and *in* denote the outgoing and incoming streams respectively.

Now the reversible device was replaced with a real industrial equipment used in our case study like evaporator, dryer, heat exchanger etc. For heaters and heat exchangers, the water present in the working fluid is not getting vaporized. There the working fluid is only brought to a higher temperature and hence the entropy change is given by:

$$\boldsymbol{S_f - S_i = mC_p ln\left({T_f}\Big/{T_i}\right)} \tag{8}$$

Then the irreversibility and efficiency are determined with the help of the resulting equations:

$$I = T_0[(S_{2a} - S_{1a}) + (S_{2b} - S_{1b})] \tag{9}$$

$$\eta = \frac{[(m_b h_{x2b} - m_b h_{x1b}) - (T_0 S_{x2b} - T_0 S_{x1b})]}{[(m_a h_{x1a} - m_a h_{x2a}) - (T_0 S_{x2a} - T_0 S_{x1a})]} \tag{10}$$

Where,

T_0 : ambient temperature (298 K)

$C_{p,milk}$ = 3.93 KJ/kg.K

$C_{p,water}$ = 4.18 KJ/kg.K

In some devices for example compressors, pumps and the thermal vapor recompression (TVR) unit, the work data which is the work done by electricity is to be counted in the estimation of irreversibility, I. The total exergy is determined by taking into account the difference in exergy caused by variation in temperature as well as difference in pressure in these devices. Thus, the exergy definition is given by the following equations:

$$e_x(T) = C_p\left[T - T_o\left(1 + \ln\left({}^{T}/{}_{T_0}\right)\right)\right] \tag{11}$$

$$e_x(P) = T_0 R \ln\left({}^{T}/{}_{T_0}\right) \tag{12}$$

$$e_x = e_x(T) + e_x(P) \tag{13}$$

From now on, the efficiency and irreversibility can be determining with the help of equation 14 and 15:

$$me_{x1} + W_{elec} = me_{x2} + I \tag{14}$$

$$\eta = \frac{W_{elec}}{[m(e_{x1} - e_{x2})]} * 100\ \% \tag{15}$$

But in evaporators, because of the heating potential of the caused vapors, the exergy of the vapors demands to be counted as a part of valuable exergy gained from the process, as provided by:

$$\eta = 100 * \left(\left(e_{x,a1} - e_{x,a2}\right) + e_{x,vap} \Big/ \left(e_{x,b2} - e_{x,b1}\right)\right)\ \% \tag{16}$$

and $$I = \left(e_{x,a1} - e_{x,a2}\right) + \left(e_{x,b2} - e_{x,b1}\right) \tag{17}$$

where,

a1: heating medium (steam/vapor)

a2: condensate

b1: incoming milk

b2: outgoing milk

whereas, in dryers no such added exergy term is used in efficiency calculation due to the absence of any vapor. This is the basic difference between an evaporator and a dryer in terms of calculating exergy efficiency even though in both these equipment the concentration of the fluid which is working increments. The exergy efficiency of the dryer is given by:

$$\eta = 100 * \left({(e_{x,a1} - e_{x,a2})}/{(e_{x,b2} - e_{x,b1})} \right) \% \tag{18}$$

and $$I = (e_{x,a1} - e_{x,a2}) + (e_{x,b2} - e_{x,b1}) \tag{19}$$

Applying these, irreversibilities and exergy efficiencies can be obtained for the various equipment in any process.

Chapter 3: Milk powder production process

Milk drying is an energy-intensive process needing hot air as a heating medium helping contemporary heat and mass transfer between the milk and the drying air. For dairy products, the most popular tool for dehydration is spray drying after evaporation, reason actuality, easy maintenance of food properties as they do not involve critical heat treatments and provide storage of powders at ambient temperature [37]. The drying operation usually takes place in three back to back stages: i) Spray chamber(first stage), where drying happens within a few seconds; ii) internal stationary fluid bed(second stage), at the conical base of the spray chamber equipped for better control of particle agglomeration and drying [38]; iii) external fluid bed(third stage), to bring the particles moisture content to the aspired level and to cool the outfeed product stream. The water molecules present in the milk escape as vapor when sufficient energy is imparted into milk by heating it at a certain temperature. The rate at which the vaporization takes place depends on a few factors, viz., milk temperature, surrounding temperature, pressure above the surface of the milk and the heat transfer rate.

3.1 Process Description

Milk powder production requires the tender removal of water from milk at a minimum cost and following strict hygiene requirements while maintaining all the needed natural properties of the milk – appearance, taste, solubility, nutritional content [32]. During the process, water present in the milk is separated by boiling the milk under decreased pressure at low temperature in a process called evaporation. The resulting thick milk is then sprinkled in a fine vapor into hot air to remove additional moisture through producing the powder.

Roughly 9 kg of skim milk powder (SMP) or 13 kg of whole milk powder (WMP) can be prepared from 100 L of entire milk [32]. The traditional process for milk powder production begins with taking the raw milk collected at the dairy factory and pasteurizing and parting it into skim milk and cream employing a radial cream separator. If whole milk powder is to be produced, a part of the cream is added back to the skim milk to standardize the fat content as per requirement.

There are two divisions in milk powder production: First is the evaporation section and second the spray drying section. The pasteurized milk at temperature 6-10 °C with about 13-14 % solids is drawn to the five effect evaporators, each followed with a preheater, which facilitates the water present in the milk gets evaporated with the help of vapor fed in the opposite direction (The hyphenated lines describe the flow direction of the pasteurized milk from left to right in the evaporation section in Figure 6 while the dotted lines describe the flow path of the steam or vapor from right to left). Because of preheating a controlled denaturation of the whey proteins in the milk simultaneously with killing bacteria, inactivating yeasts and producing natural antioxidants thereby allowing heat stability [32]. The steam which is supplied in the first stage is produced by thermally compressing a portion of the vapor produced in the third stage (Figure 6). The pressure in the five stage ranges from about 86.6 kpa in 1st stage to around 66.6 kpa in the last stage with a variation of about (4 - 6.6) kpa between any two nearby stages. The vapor generated in the evaporator-preheater assembly is divided into three parts where one part is sent to the following stage, the second to its accompanying preheater for heat exchange and a third part for CIP water heating, thereby assuring that no outside source of heating is needed (Figure 6). Condensate from the first stage, because of being in the big amount as correlated to other stages, gets settled in the pure condensate tank while for all the different stages the condensates get settled in the dark condensate tank as these condensates carry marks of solids present in the milk. The rich milk leaving the evaporation section has a temperature of about 92-93 °C and solid content of round 30 % [31].

A part of the milk leaving the five stages is rapidly cooled to about 58 °C and is supplied to the scraped surface heat exchanger where it is heated to 75°C before being provided to the spray dryer (Figure 6). In the spray dryer, atomization of the milk concentrate from the evaporator into minute droplets takes place. All this is done inside a comprehensive drying chamber in a flow of hot air at a temperature of 180-200 °C using either a series of high-pressure nozzles or a spinning disk atomizer [46]. The milk droplets are moderated by evaporation before they touch the temperature of the air so they never touch the temperature of the air. The concentrated milk may be heated earlier to atomization to decrease its viscosity and to improve the energy possible for drying. The atomized particles come in touch with hot air and water in it gets evaporated leaving a fine powder of about 5 % moisture content with a mean particle size of < 0.2 mm diameter which is received in the cellar [32]. Sometimes an additional drying takes place in a fluidized bed by which hot air is driven to remove some more water content to give a result with a moisture content of 2-5 % [32]. Some quantity of dried output product may also get directed with the exhaust air which is then removed in a high-efficiency cyclone separator and transferred back to the chamber. The milk powder produced is then received at the base of the dryer in bags or cellar and sent for a storehouse (shown in Figure 5). More details about the process conditions of the milk powder production with respect to the process flow diagram are provided in chapter 4.

3.2 Energy Efficiency Studies

In a milk powder making plant, there are several streams of them some need cooling and some demand heating. The individual stream can have different start and end temperatures, different heat capacities and flow models. When a process stream needs to be heated over a certain temperature limit, it is brought in indirect contact with another process stream which requires to be cooled over a similar temperature interval using a heat exchanger. This is more beneficial than using chilled water to cool one stream and steam to heat the other [2]. A number of heat recovery issues are there which are specific to the building dairy industry. Heat exchangers occasionally signal leaks, and heat recovery might result in corruption between two streams. This is not pleasant in milk processing and the likely solution is to isolate by pressure differential double plate heat exchangers or intermediate circuits in those types of cases. Also, many waste streams might have the tendency to carry contaminants therefore concerning the heat recovery equipment by destroying their surfaces. In the recovery of gas from waste gas streams, there is also the chance of contaminants making a fire hazard. There is also a risk of condensation because of the presence of any moisture provided by waste gas streams on lowering temperature badly. Large heat exchangers use back pressure on boilers and spray dryers and hence the capacity of original equipment to resist this back pressure should be observed. In this situation, the use of condensate at an optimal level should help in the restoration of the condensate. It can lead to advantages such as preservations of the cost of water treatment, by replacing the lost condensate, heat, to pre-warm new boiler feed water, and wastewater, because due to less condensate the wastewater produced is likewise shorter [50].

In the last few decades, some studies with respect to milk dairies were carried out in terms of exergy. However, these were mainly centered on the processing of milk [18-19] or only drying [20]. Yilirim and Genc applied thermodynamic analysis including overall exergy analysis by using different performance parameters such as exergy efficiency, relative irreversibility, etc for the milk powder production system. They showed that the overall energy efficiency was found to be around 85.4% while the exergy efficiency was coming to be as low as 57.45%. Additionally, it was determined that the evaporator and the heater have a higher stage on recovery actions [16]. Moejes and Boxtel studied the potential of developing technologies like membrane distillation, monodisperse-droplet drying, air dehumidification by zeolites etc in milk powder production and showed that these technologies had the potential to decrease the operational power consumption by up to 60 % [17]. Evaluation and optimization of the integrated solar thermal technologies designed towards cheese and yoghurt production was done by Quijera et al. [18, 21] using pinch and exergy systems. Exergy studies for the pasteurization of milk was carried out by Fang et al. [19], who then went on to optimize the process. Vidal et al. [22] explained the utility of exergy as an important parameter for the dairy industry. A New Zealand based milk powder production plant was analyzed by the authors to consider the utility of exergy technique in milk processing industry. They concluded that exergy might prove to be beneficial to design and optimize different unit processes within dairy processes after attending exergy analysis based on component-wise product input/output states. Sorgüvan and Özilgen [23] determined the exergy losses of flavored yogurt production. Several exergy based studies were carried out for different systems within the food industry and a study by Trägårdh [24] used exergy as a quality parameter. An exergy analysis of broccoli drying was performed by Marnoch et al. [25] who then studies the stage of drying parameters on the exergy losses. A new model based on the thermodynamics of drying processes was proposed by Dincer and Sahin [26]. Evaporation in food processes was discussed in [27-28], for citrus processing, studies arrangements of a wide range of evaporation systems. The modeling and operation of falling film evaporators, with reference to the dairy process, was studied by Winchester [29]. Choi et al. focused on the exergy study of thermal vapor recompression system, suggesting new designs and operating conditions [30]. From the above cases, it can be concluded that exergy analysis is a promising approach to study the energy efficiency for Company A's milk powder production process.

Chapter 4: Improving energy efficiency by process integration

In this section, the simulation of the normal performance of the milk powder plant which is the base Scheme will be performed followed by its exergy analysis. With the exergy analysis, first, the areas where the heat loss is relatively more will be determined which will be followed by improving strategies through process integration to make the entire plant much more energy efficient.

4.1 Simulation results: Base Scheme

The process conditions of milk powder production are shown in Table 1. The model shown in Figure 6 is simulated in ChemCAD software to give results, the details of which are shown in Table 2. The drying of moisture from the milk takes place in two parts as discussed prior – first in the evaporator and secondly in the dryer. In between these two sections, there is one more section where the regenerative heating and cooling of the milk takes place. The following subsections give a comprehensive picture of the simulation results in these three areas of the milk powder plant.

4.1.1. Evaporation

The evaporator is a device which is used to change liquid, for instance, water into gas/vapor below its boiling temperature, there is a different type of evaporators, the evaporator which is being used is a type of feed backward. It is a type of evaporator in which vapor and milk flow in different directions (Figure 6). The purpose why we use backward feed type stage evaporator in food processing industries like milk powder making because backward feed is advantageous and gives larger capacity than the advancing feed when the intense liquid is vicious because the viscous fluid is at the higher temperature being in the first effect. Though, this combination produces a lower economy as correlated to the forward feed arrangement. Here the milk of the highest concentration will remain in the first evaporator and will be hottest. Therefore, the viscosity of the milk will remain low,(viscosity of liquid decreases as increases in temperature) in result to a high heat transfer coefficient which, in turn, will improve the capacity of the system. So the pasteurized milk enters the evaporator at 7 °C where it gets concentrated from 15 % solids to 30 % solids. The pressure in the five stage ranges from about 86.6 kpa in 1st stage to around 66.6 kpa in the last stage with a variation of about (4 - 6.6) kpa between any two nearby stages. The partly concentrated milk leaving the evaporator section is at a temperature of 94.52 °C with an overall rise of 1.5 to 2 °C in the five stages. The quantity of evaporation in the 2nd and the 3rd stage (21.44% in 2nd and 25.61% in 3rd) were found to be significantly more than the other stages (<7%). This is due to the splitting of the vapor stream in the split fractions (Figure 6). The water which is used for CIP cleaning (Clean-in-place (CIP) is a typical method of cleaning the interior coverings of pipes, vessels, process equipment, filters, and associated fittings, without disassembling) is heated from 28 °C to 38 °C with a part of vapor produced in the evaporators. The quantity of pure condensate and murky condensate obtained are 410 kmol/h and 820kmol/h respectively. The pure condensate obtained from the first stage is sometimes used as CIP water or pumped back but it depends on boiler house requirement [51].

4.1.2. Regenerative heating and cooling

The milk leaving the evaporator division (at 94.52 °C) is then transferred to the regenerative heater where a portion of the milk is cooled to 57 °C by flash cooling and the other part is heated to 96 °C (Figure 6). The following is supplied back for a regenerative plan. The part of the milk which is leaving at 57 °C is then supplied to the scraped surface heat exchanger, where it is heated to 74 °C by steam at 400 kpa and supplied to the spray dryer for extracting the leftover moisture and concentrating it to the expected solid collection [51].

4.1.3. Spray Drying

The milk leaving the scraped heat exchanger at 74 °C enters the spray dryer from the head where it gets atomized by a range of the high-pressure nozzle. The output temperature of the dryer is maintained at about 86 °C. The vaporization of moisture content from the concentrated milk takes place due to the transfer of heat from the hot air to the milk. As a result, the atomized milk gets dehydrated from 32 % solids to 97 % solids when it comes in touch with hot air blown from the ground at a temperature of 185 °C and a pressure of 267 kpa (Figure 6). The formation of milk powder starts at 40 °C and a moisture content of 4.5 % is then received at the rear of the dryer and propelled for storage. The final moisture content of the milk powder that is obtained is about 4 % [51].

*Table 1. Process requirements for milk powder production (*source from Company A)*

Sl. No.	Condition	Value
01.	Incoming milk temperature	6-10 °C
02.	Incoming milk solid concentration	13-4 %
03.	Milk flow rate	25-30 m^3/h
04.	Pressure in the evaporators	650 mmHg in E1 to 500 mmHg in E5
05.	Pressure drop between consecutive stages	30-40 mmHg
06.	Net rise in milk temperature in the 5 stages	2 °C
07.	Rise in CIP water temperature	10 °C
08.	Temperature of milk entering scraped HEX after it is flash cooled in the regenerative heater	55-58 °C
09.	Temperature of milk entering spray dryer	70-75 °C
10.	Incoming hot air temperature	180-200 °C
11.	Dryer temperature	80-90 °C

Table 2. Simulation results of base Scheme

Sl. No.	Simulation condition	Value
01.	Temperature of milk leaving the evaporators	94.52 °C
02.	Solid concentration of milk leaving the evaporators	32 %
03.	Pure condensate collected	410 kmol/h
04.	Murky condensate collected	820 kmol/h
05.	Solid concentration of milk leaving the dryer	95.79 %
06.	Moisture content of milk powder	4.5 %

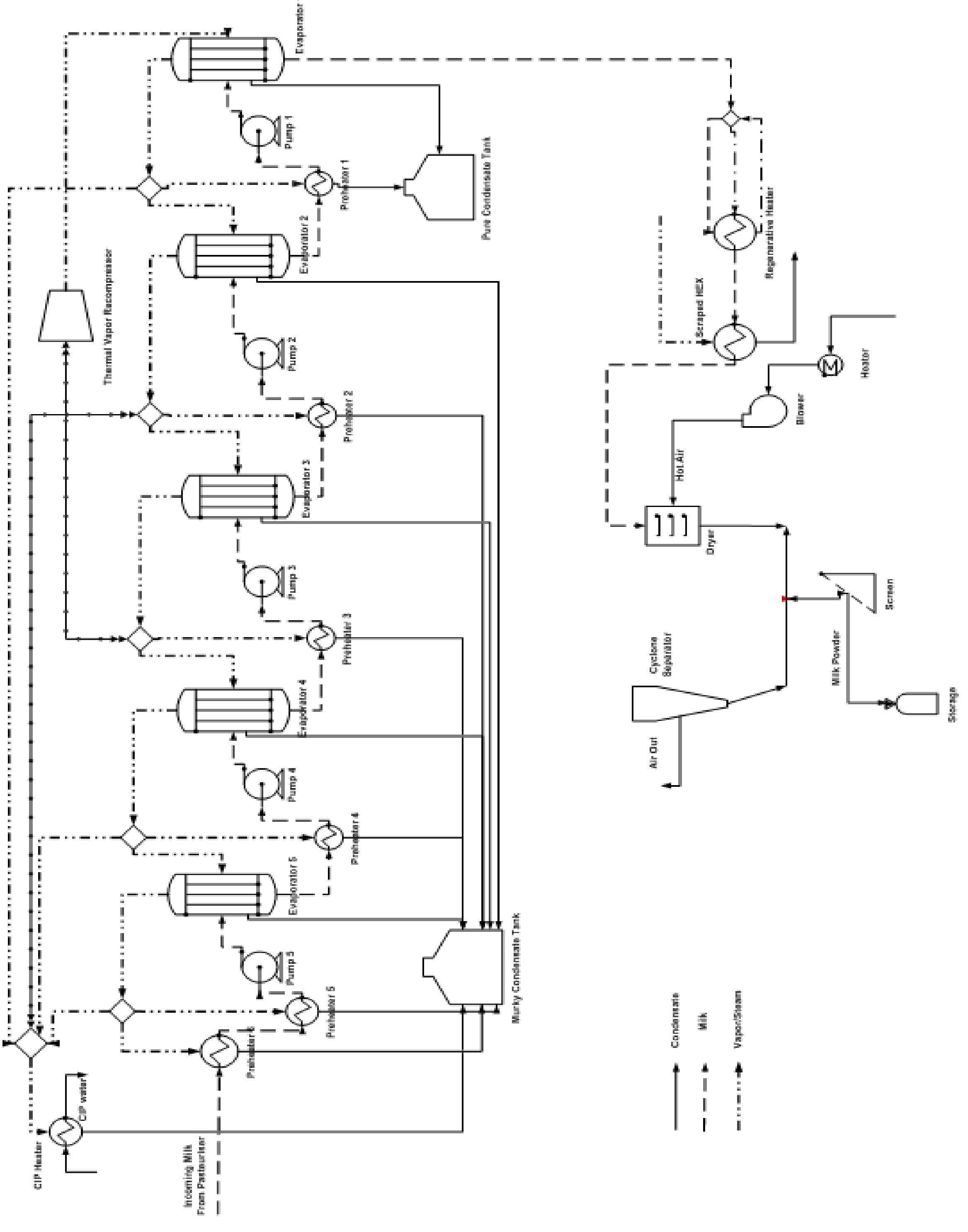


Figure 6. Process flow diagram of Base Scheme

4.2 Exergy analysis of base Scheme

We need to find the amount of heat loss in each part of the plant, exergy analysis of the base Scheme was performed with the help of the equations that we have explained chapter 2 and the outcome are given in Table 3. From our results, we can assume that some of the major devices of the plant were running on notably low energy efficiencies due to higher heat losses which results reduce the rate of the energy efficiency of the entire plant. On further examination, it was noted that larger exergy damage happens in equipment which is part of the evaporation division while the equipment presents in the drying division show relatively better efficiencies.

4.2.1. Other devices

Now taking in our account other devices such as CIP heater, preheaters, scraped surface heat exchanger and regenerative heater, the method which is used for calculating the exergy efficiency is identical for those four types of devices, the working fluids i.e. water for CIP heater and milk do not show any change of state. Firstly, need to calculate the change in entropy for both the two liquids between whom the exchange of heat is taking place. The net entropy change in both the liquids is then multiplied by the ambient temperature so that we can obtain the irreversibility or net loss in heat in this equipment, which is defined as the difference in exergy change of the cold stream and the hot stream. After that exergy efficiency can be determined by taking the proportion of the exergy obtained by the cold stream to the exergy wasted by the hot stream. By collecting the results, it was recognized that among the preheaters, the only preheaters which belong to the third (50.61 %) and fifth (43.76 %) stages showed satisfactory efficiencies while the CIP heater, regenerative heater and the scraped surface heat exchanger shown above standard exergy efficiency values (55%-70%) and so they do not require any change.

4.2.2. TVR and pumps

For devices like TVR (thermal vapor recompression unit) and pumps, we also need to focus on electricity because here the work is done because of electricity. To find the net irreversibility which is produced we need to make a stability between exergy content of the incoming and outgoing fluids and the work done because of electricity. Here the exergy is provided both by temperature and pressure because in these devices the working fluid experiences change in temperature and pressure both. We can calculate exergy efficiency as the ratio of work done because of electricity to the net difference in exergy of the working fluid.

The vapors from the third evaporators access the Thermal Vapor Recompression with a flow rate of 1754 kg/h at 90.6 °C and the steam leaves at 271.66 °C. The inlet and outlet temperature can be obtained from the steam table, the identical enthalpy values are -2.2 x 107 kJ/h and -1.89 x 107 kJ/h individually. The work done by electricity is 4.81 x 105 kJ/h. Using Cp = 4.18 kJ/kg. K, T0 = 298 K and R = 0.462 kJ/kg. K and placing these values and the process requirements in Equation (11), (12) & (13) in chapter 2, and calculating the values for ex1 and ex2. Which are -20.68 kJ/kg and 279.83 kJ/kg individually. These values were used in equation (14) & (15) to get the lost heat or irreversibility as 1.0053 x 106 kJ/h and efficiency of 31.73 %.

Therefore, the outcomes collected showed that the TVR has an efficiency of only 31.73% which is below standard considering the importance of the devices in the entire process. On the other side, most of the pumps showed above standard efficiencies (> 55-60%). Examining the result, thermal vapor recompression unit (TVR), one of the most essential parts of the process, showed considerably low efficiency became noticeable. Hence, we need to develop a strategy to improve the exergy loss in this device.

4.2.3. Evaporator and dryer

Exergy analysis which we did for previous calculation is a little same for dryer and evaporator. The hot utility which we call vapor or steam for the evaporators can be used as hot air for the dryer and their identical devices we can condensate at the exit use exhaust for the evaporator and dryer, individually. Only variation is within dryer and evaporator is that when we calculate exergy efficiency, in evaporators, because of the heating potential of the caused vapors, the exergy of the vapors demands to be counted as a part of valuable exergy gained from the process whereas, in dryers no such added exergy term is used in efficiency calculation due to the absence of any vapor. This is the basic difference between an evaporator and a dryer in terms of calculating exergy efficiency even though in both this equipment the concentration of the working fluid increases. It was also noted that between the evaporators, the third one, the one from which a portion of the vapor is transferred for thermal compression into steam, gave the least efficiency (17.17%).On the other hand, the dryer came out to be showing one of the tremendous efficiency values (68.17%) in the whole examination.

Thus, we can conclude that the efficiency of exergy differs from a large range in various sections of the milk powder manufacturing and there is a wide scope in improving the situation and hence we can improve the overall efficiency of the plant.

Table 3. Exergy analysis results for base Scheme

Sl. No.	**Equipment**	**Irreversibility (KJ/h)**	**Efficiency (%)**
01	Pre Heater 1	5.35×10^4	22.02
02	Pre Heater 2	6.615×10^4	12.58
03	Pre Heater 3	9.784×10^3	50.61
04	Pre Heater 4	1.2799×10^4	16.79
05	Pre Heater 5	1.11×10^4	43.76
06	Pre Heater 6	1.287×10^5	41.81
07	CIP heater	1.397×10^6	65.64
08	Regenerative Heater	1.532×10^6	68.94
09	Scraped HEX	7.64×10^5	55.29
10	Thermal Vapor Recompressor	1.0053×10^6	31.73
11	Pump 1	6.133×10^4	61.6
12	Pump 2	1.88×10^5	63.38

13	Pump 3	2.24 x 10^5	61.23
14	Pump 4	2.59 x 10^5	56.63
15	Pump 5	5.23 x 10^6	31.62
16	Evaporator 1	2.662 x 10^7	22.025
17	Evaporator 2	4.475 x 10^7	25.87
18	Evaporator 3	1.17 x 10^8	17.17
19	Evaporator 4	2.399 x 10^7	48.8
20	Evaporator 5	1.945 x 10^7	21.59
21	Dryer	2.09 x 10^7	68.17

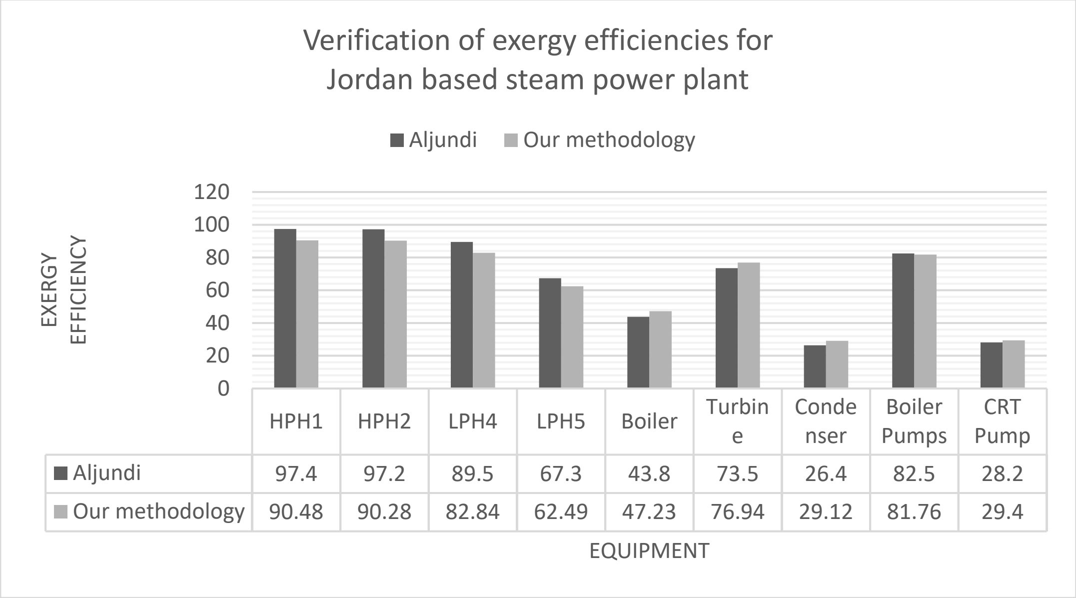
4.3 Verification

The results we have obtained after our calculations as above, we also need to verify them so for the verification we will take the help of Isam H. Aljundi's paper titled "Energy and exergy analysis of a steam power plant in Jordan"[36]. This paper is related to the exergy analysis of a dairy plant. The main objective of the paper is to analyze the process components independently and to understand the areas having higher energy and exergy losses. Therefore it is similar to the work presented in our study for milk powder production. In this verification, the input data obtained from the Jordan based steam power plant was used in the methodology followed in our work which has been already discussed. All the equipment in the steam power plant falls under the first two categories of our analysis, which means that we did not require the methodologies of evaporator and dryer for doing this exergy analysis. For the heaters, the difference in entropy was calculated from the temperatures at the initial and final state of the working fluid and these values were used in to determine the irreversibilities. The efficiency was calculated by taking the ratio of exergy improvement of one stream to exergy loss of the other stream. For the boilers, turbines, and pumps, the work done by electricity was involved in the calculation of irreversibility. As in all these devices, the working fluid has to experience both a change in pressure and a change in temperature, the total exergy is provided by exergy change because of change in temperature and change in pressure. The efficiency was subsequently calculated by dividing the work done by electricity to that of the exergy change of the working fluid.

The results of all the equipment were pretty close in the two methodologies except for HPH1, HPH2, and LPH4 where the errors are coming to be in the greater than 6 %. (This could have happened due to some misprint in the literature.) It could also be considered that only in the boiler, turbine, condenser, and CRT pump have we got our exergy efficiency values to be more than what is there in the paper. So the irreversibility and efficiency values obtained were found to be in sync with what Aljundi had obtained in his paper. The methodology verification table has been provided in Table 4 and the results are compared graphically represented in Figure 7.

Table 4. Methodology verification results

Sl. No.	**Equipment**	**Aljundi (*I*)**		**Our Methodology(*II*)**		**Error(*I* – *II*)**	
		I(MW)	**η (%)**	**I(MW)**	**η (%)**	**I(MW)**	**η (%)**
01.	HPH1	0.438	97.4	0.43889	90.48	$-8.9x10^{-04}$	6.92
02.	HPH2	0.359	97.2	0.35833	90.28	$+6.7x10^{-04}$	6.92
03.	LPH4	0.377	89.5	0.37639	82.84	$+6.1x10^{-04}$	6.66
04.	LPH5	0.295	67.3	0.29472	62.49	$+2.8x10^{-04}$	4.81
05.	Boiler	120.54	43.8	121.33617	47.23	–0.79617	–3.43
06.	Turbine	20.407	73.5	19.88723	76.94	+0.51977	–3.44
07.	Condenser	13.738	26.4	13.73766	29.12	$+3.4x10^{-04}$	–2.72
08.	Boiler Pumps	0.22	82.5	0.22193	81.76	$-1.93x10^{-03}$	0.74
09.	CRT Pump	0.331	28.2	0.33247	29.4	$-1.47x10^{-03}$	–1.2



	HPH1	HPH2	LPH4	LPH5	Boiler	Turbine	Condenser	Boiler Pumps	CRT Pump
■ Aljundi	97.4	97.2	89.5	67.3	43.8	73.5	26.4	82.5	28.2
■ Our methodology	90.48	90.28	82.84	62.49	47.23	76.94	29.12	81.76	29.4

Figure 7. Graphical representation of the verification results

4.4 Strategies to improve energy efficiency

To overcome the quantity of heat loss in the equipment and how to improve the energy efficiency of the plant, several strategies that have the potential to enhance the present condition were analyzed. As we explained earlier, it was recognized that it was not only the third stage showing the least efficiency between the evaporators but also including the thermal vapor recompression unit, where a portion of the vapor produced in the third stage is thermally compressed into steam, also showed below standard efficiency. With this analysis, we can present some strategy with some scope which leads to enhancing the current situation of the plant. Therefore, we can see two option in this situation which we can implement, one is to send the vapor generated from 2nd stage to TVR unit and second is to send the vapor to generate from 4th stage to TVR unit, in place of the third stage.

First, we put the 4th stage on our analysis. A part of the vapor produced in the 4th stage earlier which was being sent for CIP heating is now sent for thermal compression unit to steam which would then be supplied to the 1st stage as the main source of evaporation while the portion of vapor which was earlier sent for thermal compression is now assigned to the CIP heater. Now we need to simulate our new strategy resulted by its exergy analysis produced results which turned out to be below level even when related to that of the base Scheme. Before, the exergy efficiency of TVR and 3rd stage were 31.73 % and 17.17 % respectively. After this new growth, these values have further decreased to 28.96 % and 15.72 % respectively. One of the reason for such an occurrence may be connected to the fact that amount of vapor sent to CIP heater from 4th stage is lesser than the vapor from 3rd stage which is sent for thermal compression. After these two have been interchanged in the new approach, both TVR and 3rd stage have experienced more losses then what we expected. Henceforth this approach was dismissed.

Now, the 2nd stage vapor is partially sent to TVR instead of the 4th stage and the part which was earlier being sent to TVR is now being used CIP heater as earlier. Now we need to simulation our new strategy resulted by its exergy analysis produced better results with compared to the TVR and the 3rd stage as compared to the base Scheme. A complete exergy analysis showed important enhancement in a few other major devices and this, in turn, set the first strategy which could be proposed to Company A. The second strategy we can propose by using the murky condensate as a hot utility to heat up the CIP water in place of the vapors, therefore using the full potential of the vapors to evaporate the moisture present in the milk in all the five stages. These two proposed strategies, considered to bring better results when realized in the plant.

4.5 Scheme 1

It is perceived that in base Scheme, the portion of the vapor leaving the third stage that is being used for CIP heating is larger than the part that is sent for thermal compression into steam. As, for the purpose of drying, the CIP heating is not our major priority, it can be assumed that there are extents for development in this section of the plant. Furthermore, the quantity of vapor sent for CIP heating from the second stage is much larger than that from third stage (because of the split ratio at the splitters). Therefore the vapor from the second stage which was before being sent for CIP heating is now used for thermal compression to steam and the vapor from the third stage that was before being used for thermal compression is now sent for CIP heating in the new strategy, just exchanging the purpose (shown in Figure 8). The following subsections explain the simulation outcomes achieved after performing this new approach:

4.5.1 Evaporation

Following this new approach now performing in the current plant processes, the milk leaving the evaporators now has a solid concentration of 31.87%, which earlier used to be 31.15%, so little bit improvement also the milk temperature has also increased a little to 94.13 °C. The pure condensate produced from the first stage has grown from 399.97 kmol/h to 437.78 kmol/h because of the fact that the quantity of steam supplied to the first stage is more now, because of which the pure condensate received is also more. But in result, the quantity of murky condensate is reduced from 820.07 kmol/h to 804.12 kmol/h because of the fact that now the vapor which is used for CIP heating is relatively lesser which in turn ends in lesser condensate generation (Table 5). As for the exergy, the performance of TVR in this Scheme has recorded a jump from 31.73% to 47.17% which is like 9.44% while the performance of the 3rd stage is at standard with that of base Scheme (Table 6). Simultaneously with this, the first and second stage evaporators including their respective preheaters have recorded an important increase in performance (around 20.25%). The rest of the devices has displayed only small differences.

4.5.2 Regenerative heating and cooling

The partly concentrated milk from the evaporators begin to enter this division at 94.13 °C and a portion of it is repeatedly flash cooled (Flash-cooling provides incomplete water evaporation without using the product in connection with an exchange surface or different component possible to transfer energy) to its purpose value of 59.05 °C and then heated to 76.21 °C in the scraped heat exchanger furthermore supplied to the spray dryer. This explains that there are not numerous changes in the method conditions required in this region and therefore the exergy values are plus or minus at standard with that of base Scheme. The regenerative heater presently has an exergy performance of 68.37%, a bit lower from 68.94%, the value in the situation of base Scheme, while the scraped surface heat exchanger presents a small higher extension from 55.29% at base Scheme to 55.91% in this latest approach.

4.5.3 Spray drying

The point that in the evaporators, milk already got concentrated to 31.87% (0.88 % more than the base Scheme), had an immediate stage on the amount of drying as well. The concluding dried powder in this new plan had an overall moisture content of 3.88%, which is 0.62% lesser than the base Scheme (Table 5). The last solid temperature was also sustained at about 40 °C in the occupation of hot air driven from the rear of the dryer at 185 °C and 266.64 kpa. As a conclusion, the dryer efficiency improved a short from 68.17 % in the base Scheme to 69.24% in Scheme 1.

This confirms that in Scheme 1, due to enhanced efficiency of evaporation in first and second stages, the overall drying has updated. Therefore, this strategy plus or minus directed that devices which were before showing low exergy performance in base Scheme and advanced them to fair amounts. In the second Scheme, a different strategy is given which when performed with this Scheme 1 will show additional advancement in the exergy effects.

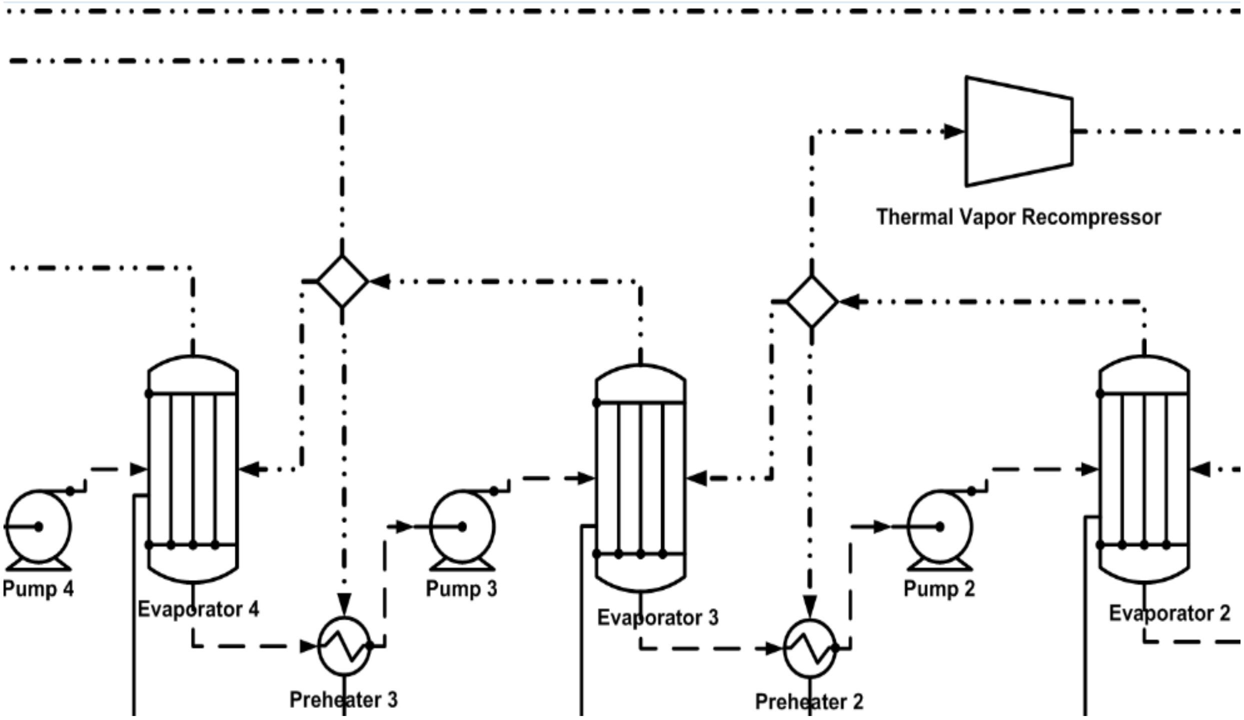


Figure 8. PFD of Scheme 1

4.6 Scheme 2

In the preceding examples, we were using the vapor generated in the evaporators to heat the Cleaning in Process water (for its 10 °C increase). But it was mentioned that alternatively of using the vapor if the condensate was used for Cleaning In Process heating (because it is not a higher priority in the drying of milk), then the energy effectiveness could be further enhanced. On performing this development in Scheme 1, it showed significant growth in the efficiency rates and decrease in the heat losses because of the case that now more quantity of vapor, which was before sent for Cleaning In Process(CIP) heating, was now used for the evaporation of the water present in the milk in the five stages. The adjustment made in Scheme 2 with regard to Scheme 1 is given in Figure 9. A complete picture of the simulation outcomes is shown in the next subsections:

4.6.1 Evaporation

If we use this new approach with the Scheme 1, has emerged in an improvement in solid concentration in the milk leaving the evaporation stages from 31.87 % solids in Scheme 1 to 33.05% solids following this mixed strategy. The complete water removal in all the five stages has more surged notably, from 52.02 % in Scheme 1 to 53.22 % under the modern Scheme. As now more quantity of vapor is being sent for evaporation, but the evaporators effects are designed with some heat transfer areas and they are able to work with some specific power. Increasing the amount of vapors for the effects doesn't mean that the evaporator will be able to process increased power due to the limitation in heat transfer area of the evaporator. But here we are not working about the evaporator design but about the possibilities of increasing energy efficiency of the plant. For implementation of the improved schemes the design of the evaporators should be checked if their heat transfer area is enough to process increased amount of vapors. The condensates obtained in both the pure and murky condensate tanks have raised (pure condensate: 452.92 kmol/h from 399.7 kmol/h in base Scheme and murky condensate: 870.37 kmol/h from 820.07 kmol/h in base Scheme). The final temperature of the Cleaning in process water, which is now 35.10 °C, is also seen to have developed a little in this Scheme (34.13 °C in base Scheme and 34.78 °C in Scheme 1). From the exergy prospect, important growth has been noticed in the 3rd stage, both in the evaporator also in its respective heater. Compared to Scheme 1, where the efficiency values of the 3rd evaporator and preheater were 17.21 % and 46.42 % respectively, these values have now surged to 22.02 % and 49.97 % individually (Table 6). All the preheaters following this fresh approach have revealed satisfactory improvement while the rest of the devices displayed minor changes.

4.6.2 Regenerative heating and cooling

The milk now transmits the evaporator at a temperature of 94.02 °C, which is a small increase from Scheme 1 where the milk leaving the five stages and joining this sector had a temperature of 94.13 °C. A portion of the milk is cooled to its intended value of 59.05 °C and supplied to the scraped surface heat exchanger where it is heated to 76.21 °C before being supplied to the spray dryer. The exergy efficiency of both the regenerative heater and the scraped surface heat exchanger revealed a slight decline, and it is unimportant and will not affect the overall exergy Plan of the entire plant.

4.6.3 Spray drying

The advancement in solid concentration in the evaporation sector had a straight influence in the ultimate moisture content of the milk powder. There had been a rise of 5.5 % in the overall solid mass in Scheme 2 from the base Scheme, as a result of which the milk powder moisture content has decreased from 4.5 % in base Scheme to 3.95 % in Scheme 2 (shown in Table 5). The final solid temperature remained within its intended limit of about 39.5 °C. All these have appeared in an improvement in the dryer performance, from 68.17 % in base Scheme and 69.24 % in Scheme 1 to 68.37 % in this mixed approach.

These two Schemes explained over simply represent how process integration helps to improve the overall performance of any process. The simulation outcomes of the two recommended strategies with respect to the base Scheme are shown in Table 5 while the exergy results of Scheme 1 and Scheme 2 with respect to the base Scheme are shown in Table 6. A graphical representation representing the corresponding study of all the three Schemes for that device which show notable developments has been shown in Figure 10.

Table 5. Simulation results of Scheme 1 & 2 with respect to base Scheme

Sl. No.	Condition	Value with respect to base Scheme	
		Scheme 1	**Scheme 2**
01.	Temperature of milk leaving the evaporators	+0.62 °C	+0.21 °C
02.	Solid concentration of milk leaving the evaporators	+0.88 %	5.5 %
03.	Pure condensate collected	+37.7 kmol/h	+52.6 kmol/h
04.	Murky condensate collected	–16.49 kmol/h	+49.22 kmol/h
05.	Solid concentration of milk leaving the dryer	+0.62 %	+0.197 %
06.	Moisture content of milk powder	–0.62 %	–0.197 %

Table 6. Exergy results of Schemes 1 & 2 with respect to base Scheme

Sl. No.	Equipment	Irreversibility (KJ/h)		Efficiency (% change with respect to base Scheme)	
		Scheme 1	**Scheme 2**	**Scheme 1**	**Scheme 2**
01	Pre Heater 1	3.13×10^4	2.981×10^4	+16.74	+19.11
02	Pre Heater 2	3.97×10^4	3.24×10^4	+19.81	+24.76
03	Pre Heater 3	1.01×10^4	9.82×10^3	–3.24	–0.59
04	Pre Heater 4	1.52×10^4	9.88×10^3	–0.34	+6.92
05	Pre Heater 5	1.48×10^4	1.003×10^4	–0.84	+0.43
06	Pre Heater 6	1.462×10^5	9.76×10^4	–0.61	+3.59
07	CIP heater	1.52×10^6	1.453×10^6	–3.86	–2.29
08	Regenerative Heater	1.58×10^6	1.61×10^6	–0.24	–0.73
09	Scraped HEX	7.42×10^5	7.428×10^5	+0.74	+0.66
10	Thermal Vapor Recompressor	1.001×10^6	1.0007×10^6	+14.11	+14.86
11	Pump 1	5.84×10^4	5.37×10^4	+0.70	+0.95
12	Pump 2	1.823×10^5	1.83×10^5	+2.13	+2.09
13	Pump 3	2.49×10^5	2.52×10^5	–0.34	–0.47
14	Pump 4	2.81×10^5	2.823×10^5	–0.22	–0.74
15	Pump 5	5.47×10^6	5.561×10^6	–0.29	–1.22
16	Evaporator 1	2.083×10^7	2.004×10^7	+22.02	+24.75
17	Evaporator 2	3.477×10^7	3.238×10^7	+22.31	+25.29
18	Evaporator 3	1.1743×10^8	1.159×10^8	–0.58	+4.58
19	Evaporator 4	2.469×10^7	2.35×10^7	–0.66	+0.64
20	Evaporator 5	1.98×10^7	1.47×10^7	–0.48	+5.34
21	Dryer	2.04×10^7	2.01×10^7	+0.82	+1.50

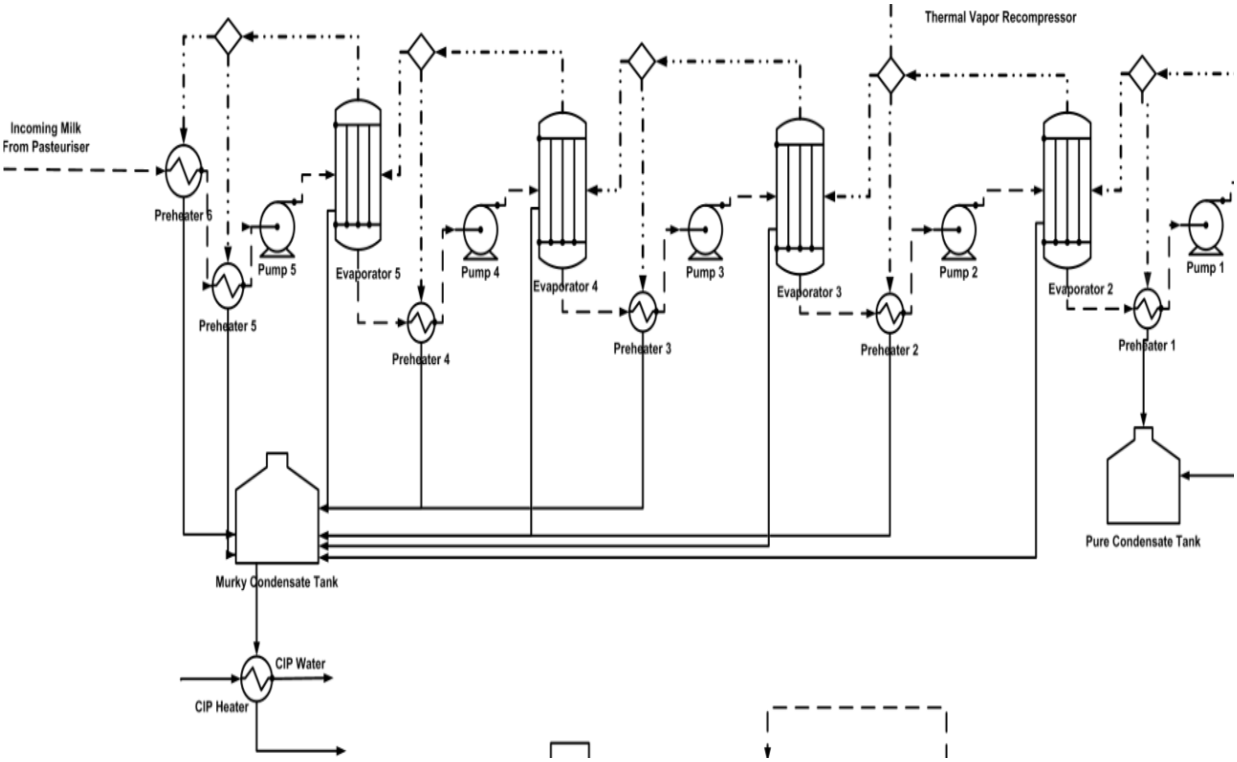
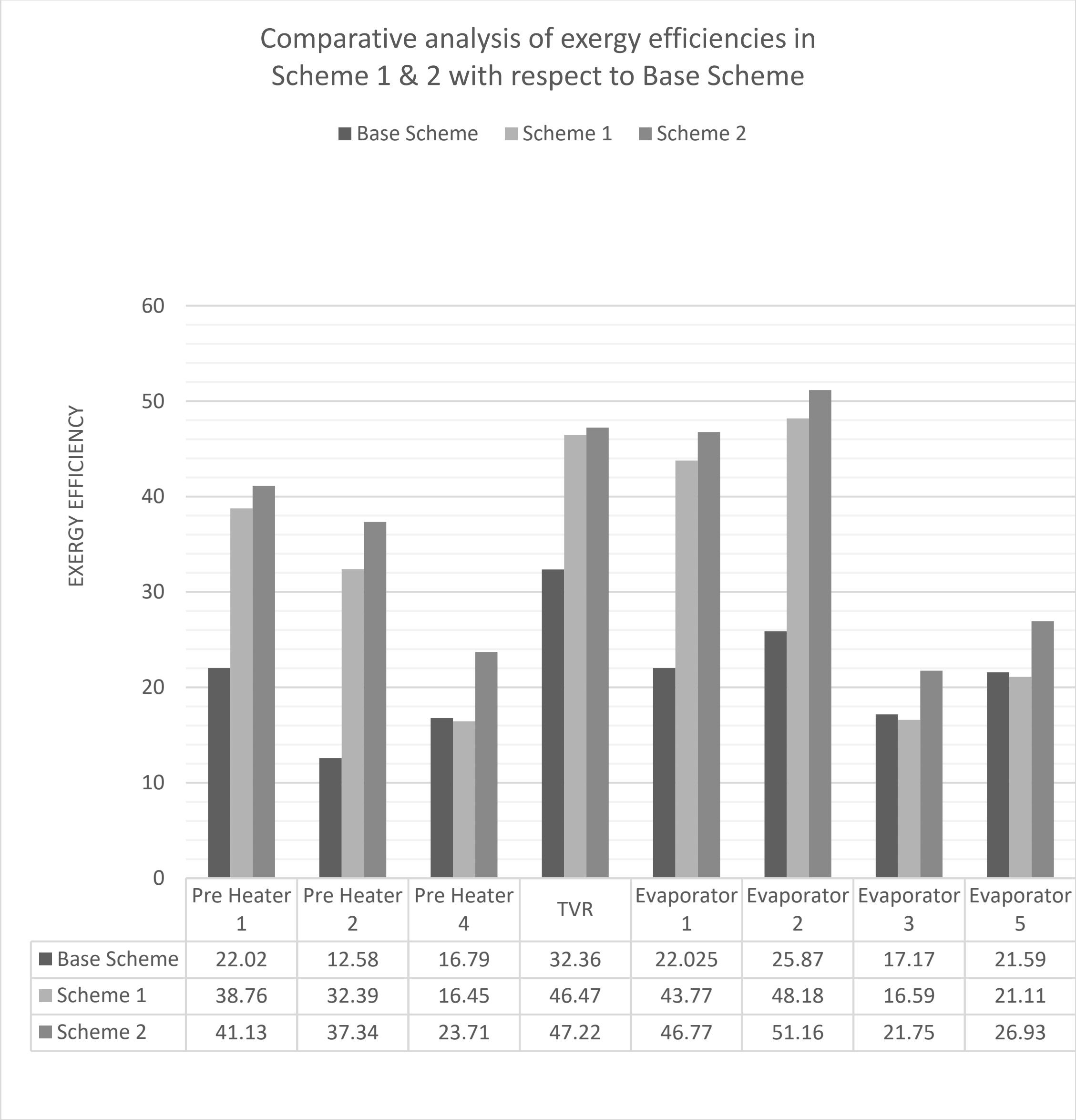


Figure 9. PFD of Scheme 2



	Pre Heater 1	Pre Heater 2	Pre Heater 4	TVR	Evaporator 1	Evaporator 2	Evaporator 3	Evaporator 5
■ Base Scheme	22.02	12.58	16.79	32.36	22.025	25.87	17.17	21.59
■ Scheme 1	38.76	32.39	16.45	46.47	43.77	48.18	16.59	21.11
■ Scheme 2	41.13	37.34	23.71	47.22	46.77	51.16	21.75	26.93

Figure 10. Graphical representation of the three Schemes

Chapter 5: Other Consideration

Apart from exergy analysis we could use consider other methodology for optimization of manufacturing plant, like Six Sigma.

Six Sigma-based structure using define-measure-analyze-improve control (DMAIC) the methodology is selected through the utilization of design of experiments tool to concentrate on customer's demands to improve the quality aspect of milk powder production process in milk powder manufacturing company [45].

The integrity of Six Sigma plays the best role for facilitating any dairy company to define the problem and minimize its goal through a well-organized procedure.

Six Sigma has been examined to be a well-organized, commanding system to continuously enhance the processes and produce new products by using efficient scientific and statistical tools and methods. So, after optimizing plant with exergy analysis we can use a Six Sigma-based structure using DMAIC methodology to advance the quality aspect of the milk powder production process in the company.

We need to study to see the possible area in which Six Sigma DMAIC approach can help to improve the quality of milk powder production process. This case can assist managers of the company to apply the Six Sigma method to discuss complex problems in other processes, where problems individually are not clear.

Basically, in six sigma we focus on variation and defects, we can eliminate the defects but we cannot eliminate the variation but we can minimize the variation, for example in the production of milk powder we face problems regarding the Ph. of milk and milk powder is 6 to 7. Which we can explain in the following illustration below

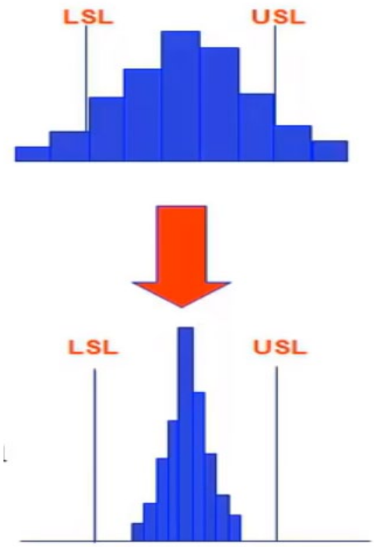


Figure 11. Explanation for LSL AND USL in histogram

So, if we consider LSL (lower specific limit) as 6 and USL (upper specific limit) as 7. So, in first case we see we have lots of variation and some values are out of the limits. So, after using six sigma we can control variation (figure 11) within the limits and ideally try to eliminate them. It’s one example to show how we can implement six sigma in the process to optimize and improve the process quality of the process and similarly we can use six sigma methodology in other problem in our process by Defining –Measuring – Analyzing –Improving and Controlling (DMAIC).

Chapter 6: Economy

In the previous chapter we have discussed some ways how to optimize the milk powder production line by making changes in process flow diagram and specially in evaporator but according to the previous comments the next step should be verifying the ability of the each evaporator effect for the proposed design changes, specially heat transfer area of each affect should be properly designed, which is not possible without deeper investigating of the plant for which we need permission from the company A and this is not the task of the thesis because we do not know the extent of necessary changes in design of the evaporators station so we are not able to set the necessary investment for proposed improvement. For this reason, it is decided to skip the economic study from this work and second reason because we do not have permission from Company A (Madeta) for this.

Chapter 7: Summary

With this report we can improve or optimize the milk powder production plant or any other plant with the help of six sigma and exergy analysis. Firstly we create a model of a milk powder plant of Company A dairy and then simulated with the help of Chemcad software by which we get to know the performance of all the devices under normal operation, then we examined where we can improve the efficiency of the device in order to make overall efficiency of plant better. On the basis of values, we get by simulating we proposed two strategies and if we implement those strategies it can lead to important improvement in overall efficiency of the plant. Then we try to explain how we can implement six sigma methodology in food processing industry and benefits of six sigma which can improve the quality of the product.

The overall approach of improving energy efficiency and quality of the product can lead to huge profit to the company if company implement the recommended changes in process flow diagram for energy efficiency and six sigma for quality improvement rejection control also it is beneficial to the environment.

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