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EXERGY ANALYSIS ON MILK PROCESSING PLANT USING CYCLE- TEMPO SIMULATOR

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Abstract

The novelty of this work is, simulation of a dairy plant which is performed in a cycle-tempo simulator and operational parameters of the Rankine cycle were optimized using the Exergy and energy concept. The aim is to investigate the exergetic efficiency and exergy destroyed within each component in the plant and the exergy efficiency is determined to study the irreversibility of the system and identify the chances for the enhancement of the power system. Based on the result obtained from the analysis, the exergy efficiencies of the steam generation system were determined to be about 37.52 %. The main exergy loss has occurred in the boiler and the steam turbine in the system. Further, improvements this review highlighted some of the areas like using heat exchanger for reheating by using waste heat for existing dairy plant.

Keyword:

Dairy milk plant, Energy, Exergy, Steam Generation Process, Cycle Tempo Software.

1. Introduction

Dairy processing is one of the most vital roles in the food industry. It contains valuable nutritional and health-beneficial compounds. In addition to this, this sector has a significant contribution to the creation of jobs and a substantial contribution to economic growth in both developed and developing countries. According to reports, India's dairy industry is the largest in the world, uses over 62 billion m^3 of freshwater annually, and is anticipated to use more than 400 billion m^3 by 2025 (sustainability outlook, 2014). According to the Central Pollution Control Board's (CPCB) report on the state of water quality, India's surface water quality has reached an alarming level (CPCB India 2011). In this context, India's sustainable water consumption will soon become a main priority. The largest dairy cooperative in India is Amul Dairy. Milk, ghee, butter, flavor-added milk, and milk powder are all processed there. Each year, this factory uses about 6 million m^3 of water. Due to the fact that the dairy business is a part of the food processing industry, the factories must uphold strict cleanliness standards. Dairy plants typically include cleaning-in-place (CIP) systems to ensure effective and automatic cleaning and control the losses to identify the energy and exergy analysis for milk plant utilizing statically and optimizations tool in order to keep these requirements.

Carnot introduced the idea of an extensive exergy analysis in the year 1824; Clausius work came in the year 1865. The First Law of Thermodynamics (first law of analysis) is used to determine a system's efficiency, whereas the Second Law of Thermodynamics (exergy analysis) is based on the idea of irreversibility and entropy production [1]. Researchers usually use the first law of analysis to calculate energy losses by taking advantage of the enthalpy balance over thermal power. Exergy analysis as a concept has recently been more well-known as a result of the first law analysis's inability to adequately predict a power plant's performance. Exergy analysis primarily attempts to identify the sources of exergy losses and analyze the quality of PPs. A system's flaws can be identified by exergy analysis; this cannot be done using first law analysis. Exergy analysis gives an efficiency assessment of each system's distinct parts in addition to identifying the irreversibility inside a system. Process engineers can use the results of exergy analysis to improve and create ideal TPPs.

The Gurtur et.al [2] focused on the exergy analysis of a cogeneration fluidized bed boiler created for the manufacture of salt. The maximum loss expected in the turbine and boilers was published in a different study by [3] on the exergy analysis in an SPP. This study also further revealed the impact of external factors on the plant's performance. focused on the exergy evaluation approach. Kaushik et al. [4] presented further details about this technique before coming to the conclusion that the boiler experienced the greatest amount of energy loss. Rosen & Scott reported on some more study on the exergy and energy of SPP and found that the boiler had maximum exergy and energy efficiencies of 95% and 50%, respectively.

The First Law of Thermodynamics, which states that only energy factors are taken into account, is the basis upon which the majority of power generation and dairy systems are planned and executed [5]. The energetic conditions to get both the quality and amount of energy must, however, be included in the actual usable energy loss [6]. To get more precise data and outcomes, thermodynamics study of power plant performance must be done energetically and exegetically. According to Fabian Buhler et al(2018) [7] report, the milk power plant's energy and exergy analysis. The utilities and spray dryer had a high rate of energy destruction, according to the exergy study, and the exergy losses from these devices were quantified. The significant proportion of preventable exergy destruction in heaters and coolers is revealed by the advanced exergy analysis. Isam H. Alijundi (2008)[9] gave a description of the energy and exergy analysis of the Al-Hussein power plant in Jordan and conducted a separate analysis of each system component to identify the areas with the greatest energy and exergy losses. In this article from 2013 discusses the thermo economic study of a combined cycle power plant. This methodology's primary goal is to determine the Exergy Production Cost (EPC) of the combined cycle plant under investigation.

Exergy analysis, as opposed to standard energy analysis, can determine the actual energy losses of diverse industrial plants more accurately in order to diagnose and promote energy-saving solutions. As a result, several research projects have been carried out throughout the years to analyze and optimize energy systems using the exergy idea. As a result, the purpose of this study was to provide a thorough energy analysis based on actual operational data of a long-life milk processing plant. The steam generator, above-zero refrigeration system, milk receiving, standardization, and pasteurization lines were among the four primary lines of the plant that were included in this investigation. More specifically, all plant subcomponents involved in the processing of milk were examined to ascertain their energy efficiencies and rates of energy degradation.

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2. Materials and methods

Cow milk dominates the global milk market, followed by buffalo milk. Asia is the largest producer, accounting for 30% of global production, followed by the EU (28%), North and Central America (18%), South America (9%) other European nations (9%), Africa (5%), and Oceania (5%). Food must be made from the milk of cows, buffalo, goats, or other animals in order to be called dairy products. The dairy industry produces products like ice cream, liquid milk, milk powders, cheese, butter and yogurt. The ultimate content of milk is influenced by a number of elements, including genetics, breed, environment, lactation stages, parity, and nutrition [8]. Calcium, potassium, magnesium, phosphorous, salt and iodine are among the vital minerals and vitamins found in milk and dairy products (the fat-soluble vitamins A, D, E, K and B1, B3, B6, B12). Table 1 shows the general composition of cow milk. The basic steps in the development of milk plants are depicted in Figure. 1. The weighbridge is how milk is delivered to the dairy processing facility and the weight of the milk is noted down. At the same time, information is wirelessly downloaded from an onboard computer to a data capture system that stores records of the temperature and quantities of milk gathered from each farm. A temperature of 4-6°C is good. Each supplier at the source automatically collects milk samples using sterile containers, which are then transported to a lab technician for a complete evaluation. Lower quality ratings are given to milk that differs from typical milk in terms of composition, flavor and odour. Additionally, the technician collects a composite sample from each compartment in the refrigerated vehicle, which is divided into sections to lessen milk sloshing. Acidity, antibiotics, additional water, extra fat and protein content all are tested in the samples from each compartment.

Table 1: Overall structure of milk and milk powders

	Cow's milk %	**Skim milk powder (SMP) %**	**Whole milk powder (WMP) %**	**Acid whey powder (WP) %**
Moisture	85.5–89.5	3.0–4.0	2.0–4.5*	3.5–5.0
Fat	2.5–6.0	0.6–1.5	26.0–42.0	1.0–1.5
Protein	2.9–5.0	34.0–37.00	24.5–27	11.0–14.5
Lactose	3.6–5.5	49.5–52.0	36.0–38.5	63.0–75.0
Minerals (ash)	0.8–0.9	8.2–8.6	5.5–6.5	8.2–8.8

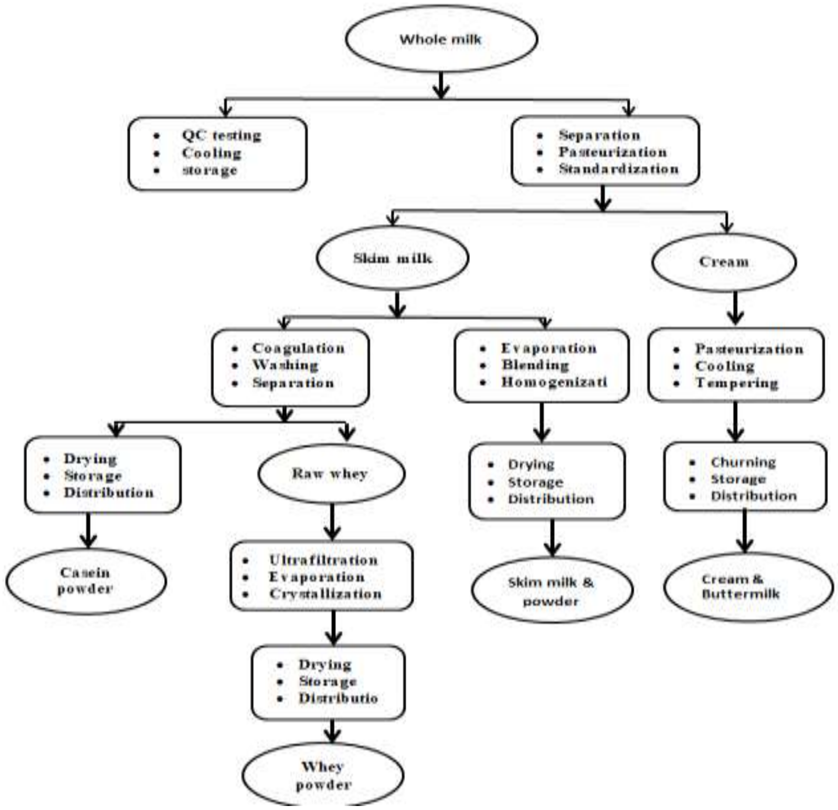

Figure. 1: Outlines of basic processes for the production of milk plant.

2.1. Statically analysis using cycle tempo software

The thermodynamic modeling and optimization of systems for the production of electricity, heat, and refrigeration are done using the flow chart computer program Cycle-Tempo. Such systems frequently consist of numerous interconnected cycles, each of which is made up of (occasionally any) various apparatuses. Pipes join these devices together, creating a complicated network of mass and energy flows. Calculating the size of the relevant mass and energy flows in the system is Cycle-main Tempo's goal. Depending on the context, there may be a variety of apparatus types and interconnections. With the help of the program's many models for tools and pipes, you can create your model of the necessary system. Compared to many other applications that are currently available, where system settings can only be changed to a small or nonexistent level, this almost unlimited flexibility is a considerable advantage.

2.2 Energy analysis

When Newton made assumptions about kinetic and potential energies, the concept of energy was first introduced in mechanics. It took until the middle of the 19th century for energy to become recognized as a unifying term in physics, and its development is regarded as one of the century's greatest scientific advances. Though it appears inherently clear to understand, the idea of energy is so familiar to us now that we frequently struggle to define it accurately. Energy is a scalar quantity that cannot be directly observed but can be measured indirectly and recorded. It is challenging to estimate a system's energy in absolute terms, but it is quite simple to assess energy change. Energy can be released via chemical and atomic reactions and is also connected to the structure of matter. Energy has always been used to help people meet their needs, and civilizations have emerged throughout history as a result. The first law of thermodynamics determines how much energy there is.

The maximum reversible work that a system is capable of delivering as it moves closer to a state of equilibrium with the environment, with any heat transfer occurring only with the environment, is used to calculate the thermomechanical exergy associated with that state. The standard atmosphere or environment used in this study is 298.15 K and 1.01325 bar, and this condition of equilibrium is also known as its dead state at T0 and P0 (1 atm). An EA is typically used to locate, source, and quantify real thermodynamic inefficiencies in process facilities like power plants [9]. Taking into consideration simply changes in kinetic and potential energy, the specific flow. The specific flow exergy of a fluid at any cycle is given by the equation

$$E = (h_1 - h_0) - T_o(S\text{-}S_o) \tag{1}$$

The Exergy change between these two states gives the reversible work as fluid transitions from an input state to an exit state, as shown below. The net exergy efficiency is calculated by the following equation:

$$e - e_o = (h_{out} - h_{in}) - T_o(S_{out} - S_{in}) \tag{2}$$

$$n_{th} = \frac{(exergy\ out) - (aux.power)}{(exergy\ absorb)} \times 100\% \tag{3}$$

3. Results and discussion

During this whole study, the figures and tables explain the results of the present work. The mathematical model developed in this study was used to calculate the results for each energy and exergy analysis. Furthermore, they are portrayed diagrammatically to give a clearer picture of the relationship between the factors in the power cycle. Based on their state number, the streams of the steam generating system's temperature, pressure, mass flow rate and exergy rate are represented in table 2. Figure 2 shows that the energy rate is high for the fuel at 28 °C and 120 psi, whereas other state values are reduced due to the high temperature and pressure in the system when the dairy plant is operating. The energy efficiency of each sub element in the steam-generating system is shown in Fig.3, with the steam trap having the highest energy efficiency and the lowest inflow and outlet energy.

Table 4 shows the exergy destruction rate, exergy efficiency and inlet as well as outflow exergy rates for each sub-component of the pasteurization system. Based on the study, the boiler and air compressor subsystem had the highest destruction rate (89%). Figures 4 and 5 shows the pasteurization system exergy rate, destruction and efficiency. The results that were observed are dependent on heat and mass transport, quick chemical reactions, quick water vaporization and

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extensive mixing processes during fuel combustion and water vaporization. It is important to note that oxygen enrichment, air preheating and lowering the amount of combustion air can all help to marginally reduce the amount of energy destroyed by industrial boilers. By keeping the flame temperature at higher values and the temperature gradient in the combustor at lower values, these can lower the irreversibility rate. However, each of the abovementioned conditions has its own disadvantages, such as higher boiler outlet hot gas temperatures and greater heat loss rates from the boiler frame to the surrounding air. Moreover, preheating the feed water using the outflow gas's heat might aid to boost an industrial boiler's efficiency. Turbulators can be installed in fire-tube boilers to increase their exegetic efficiency.

Based on their state numbers in table 5 and 6 the fluid type, temperature, pressure, mass flow rate and energy rate for the streams of the above-zero refrigeration system are reported. The highest exergy destruction rate belonged to the ice-water tank, according to a compilation of the intake exergy rate, outlet exergy rate, exergy destruction rate and exergetic efficiency of each subcomponent of the above-zero refrigeration system using actual operational data. It can be related to the significant and quick heat transfer that took place in this component. The condenser and fan combination was found to have the highest exergy destruction rate due to the significant heat and mass transfer. The compressor had the third-highest exergy destruction rate (196.84) as a result of the considerable mechanical work required to compress the refrigerant. It is noted that the use of a variable-speed drive (VSD) controller can greatly enhance the energetic performance of refrigerant compressors in the dairy business. Additionally, the ammonia separator had the highest exergy efficiency of the system due to its reduced exergy destruction rate when compared to the total incoming exergy. The pump also had the lowest energy efficiency of the system's three pumps since it destroyed energy at the highest rate.

Table.2: Energy rate analysis of steam generation system

Number	Fluid type	Temperature (ºc)	Pressure (kpa)	Mass flow rate (Kg/s)	Exergy rate(KW)
A	Air	28	101.3	6	0.14
B	Fuel	28	120	0.387	18869
C	Steam	180	1135	4.95	4049.82
D	Steam	143	401	4.95	3851.32
E	Steam+water	139	351	4.95	690
F	Water	117	181	4.95	258.47
G	Smoke	95	601	6	845
H	Water	95.35	1000	6.30	132

Table.3: Exergy efficiency of the each subcomponent of the steam generation system

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Component	Inlet exergy (kW)	Outlet exergy (kW)	Exergy destruction (kW)	Exergy efficiency (%)
Boiler and compressor	19108	6116	12395	27.8
Presser reducer	4145	3405	740	82
Steam trap	735	671	64	91
Air pump	69	59	10	44
Water pump	218	201	17	37

Table.4: Exergy efficiency of the each subcomponent of the pasteurization system

Sub component	Inlet exergy (kW)	Outlet exergy (kW)	Exergy destruction (kW)	Exergy efficiency (%)
Milk Pump(I)	10	8	2	31
Chiller(II)	40	38	2	79
Raw Milk Tank(III)	21	17	4	80
Heat Exchanger(V)	551	535	16	89
Cream Separater(VI)	17243	17233	10	54
Homogenizer(VII)	39	12	27	9.8885
Holding Tube(VIII)	101	100	1	98
Balance Tank(IX)	24	17	1	98

Table.5: Exergy rate for the streams of the above-zero refrigeration system

Number	Fluid type	Temperature (ºC)	Pressure (kPa)	Mass flow rate (kg/s)	Exergy rate(kW)
B	Ammonia(gas)	45	1241	1.3	2082.94
C	Ammonia (liquid+gas)	30	300	1.3	1892.46
E	Ammonia(liquid)	28	131	100	38.97
F	Water	28	131	100	38.97

Table.6: Exergy efficiency of each subcomponent of the above-zero refrigeration system.

Sub component	Inlet exergy (kW)	Outlet exergy (kW)	Exergy destruction (kw)	Exergy efficiency (%)
Compressor(I)	2279.7	2082.9	196.84	84.38

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Condenser(II)	2184.34	1892	291	86
Receiver(III)	10541	10458	86	90
Ammonia separator(IV)	10541.72	9681	2949	76
Ice-water tank(v)	12631.67	9681.44	2649.70	76.65
Pump(VI)	9470.67	9458.77	11.90	63.28
Expansion valve(VII)	1892.46	1784.06	108.40	94.27

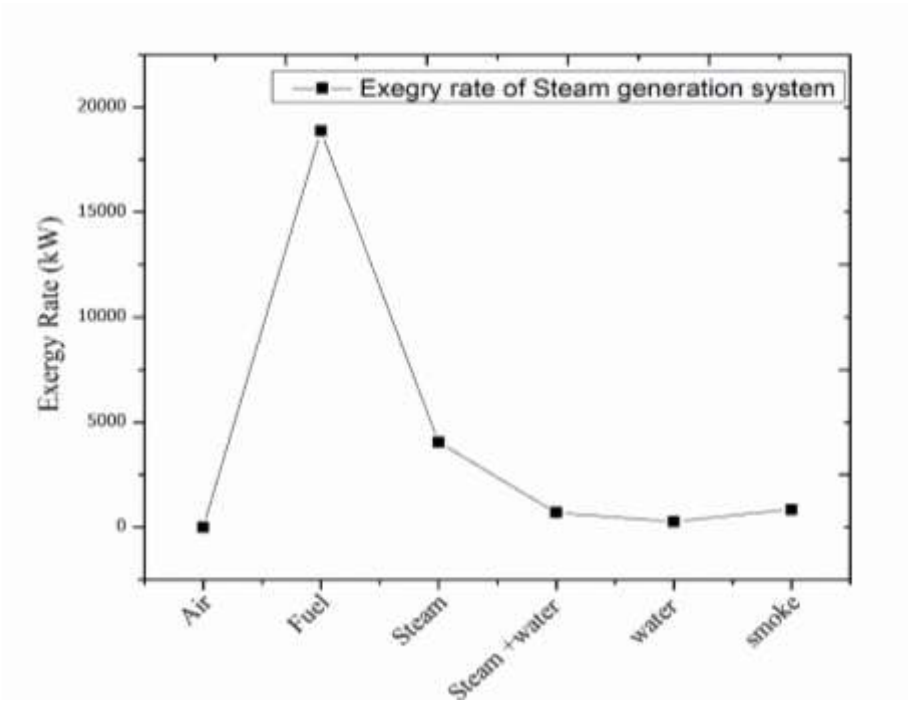

Figure. 2: The exergy rate of each sub component in the steam generation system

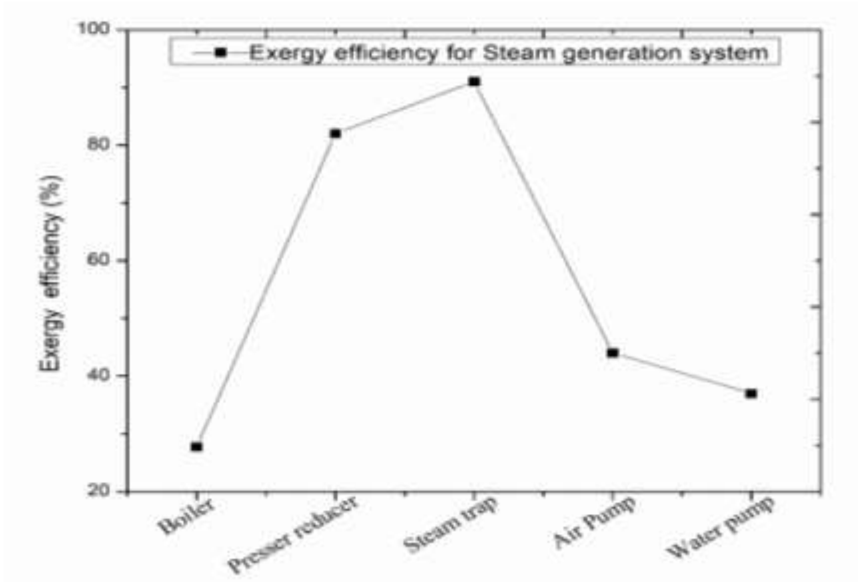

Figure. 3: The exergy efficiency of each sub component in the steam generation system

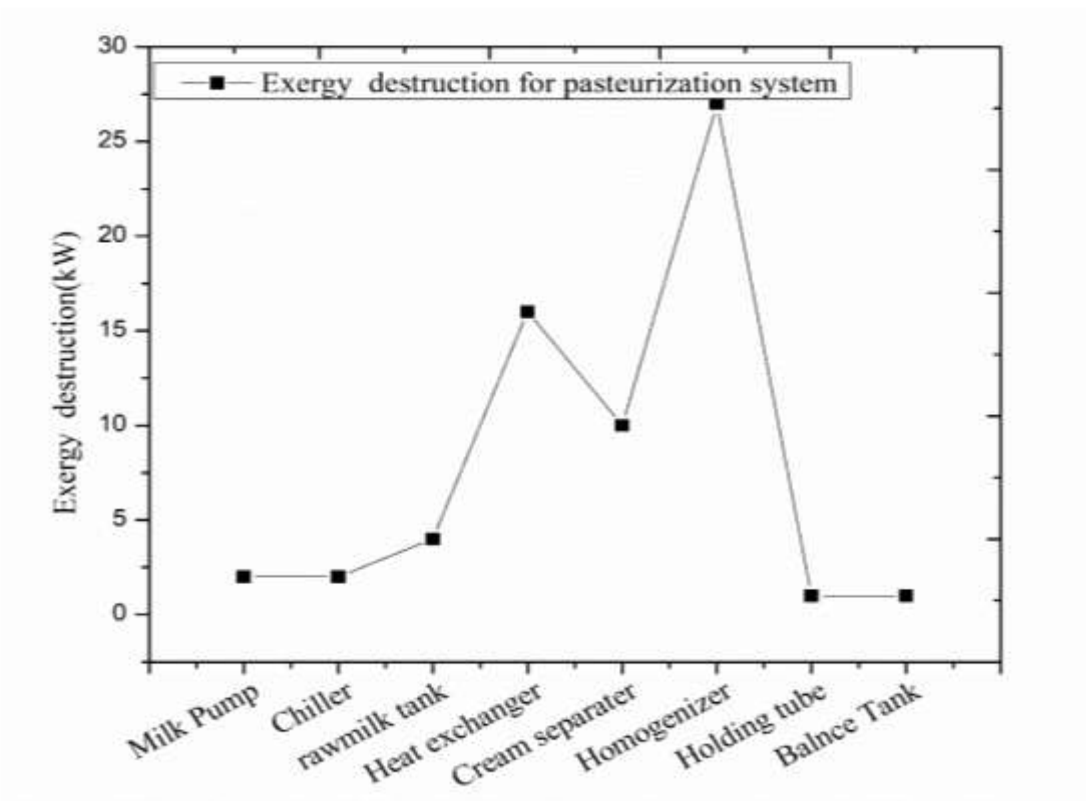

Figure. 4: The exergy distruction of each sub component in the pasteurization system

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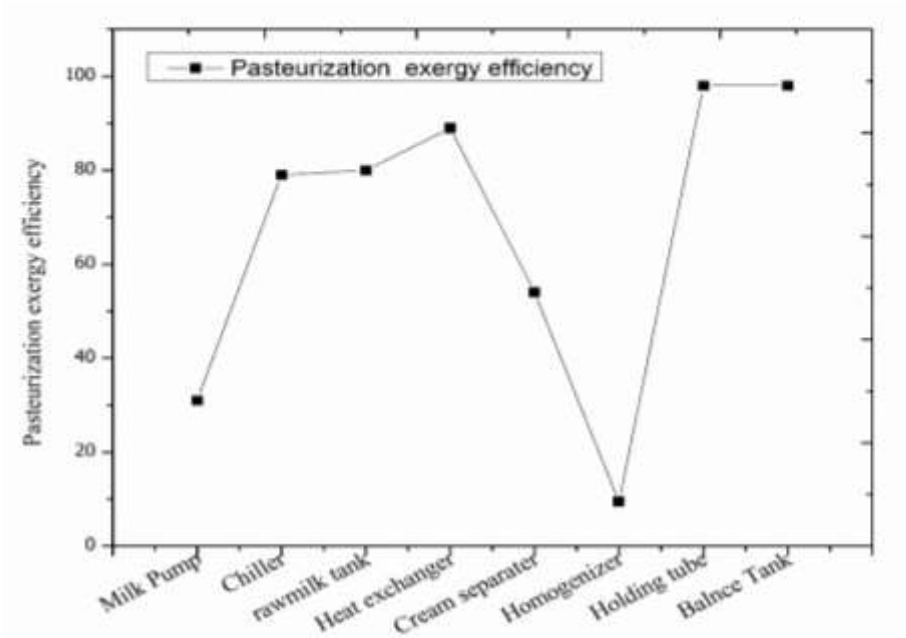

Figure. 5: The exergy efficiency of each sub component in the pasteurization system

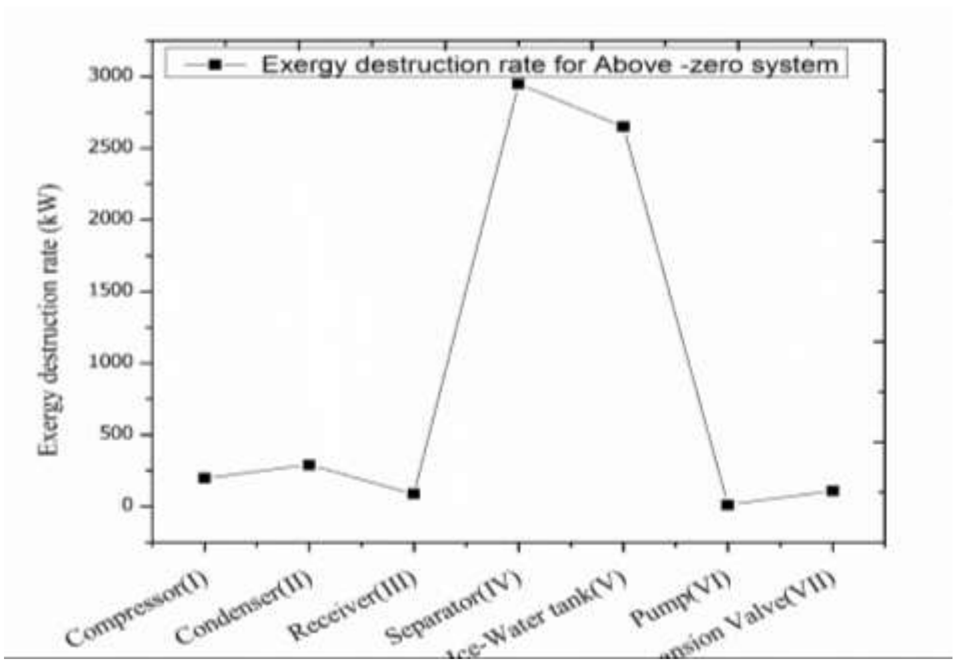

Figure. 6: The exergy destruction of each sub component in the above-zero system

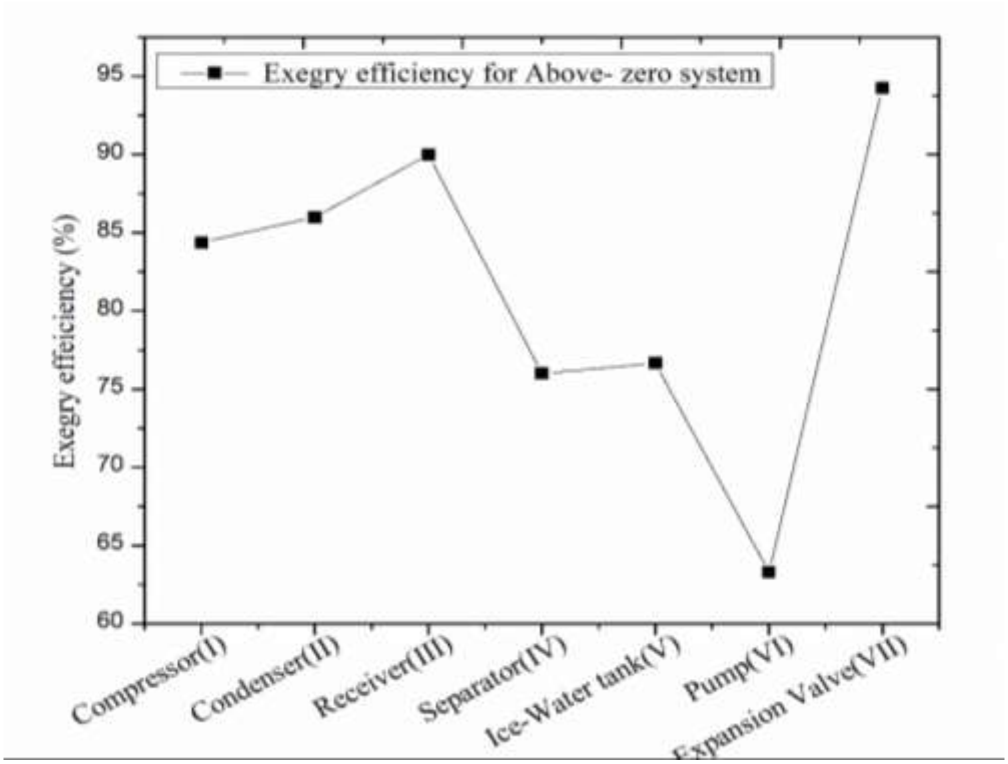

Figure. 7: The exergy efficiency of each sub component in the above-zero system

3.1.Comparison of the simulated analysis and standard cycle analysis

Using cycle tempo software, Fig. 8 shows the typical flow diagram of a dairy facility. Total energy, mechanical energy and chemical energy were measured using a flowchart and are shown in table 7 below. Additionally, exergy analyses for total, mechanical, and chemical exergy was obtained using flow diagrams. The temperature and pressure utilized in dairy plants, according to the table, have larger energy and exergy losses. The standard cycle was altered with variable temperature and pressure to solve the issues with the dairy plant and enhance plant efficiency. Using the cycle tempo tool, a simulation was run at various pressures and temperatures and the results were compared to a conventional cycle. When compared to a stranded cycle diary plant, efficiency increased and energy losses decreased when lower temperatures and pressures were applied.

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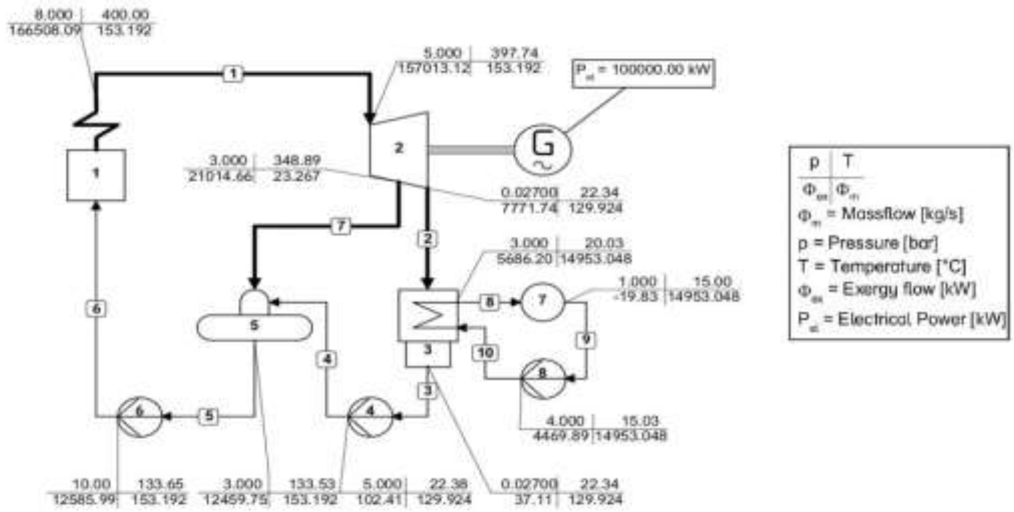

Figure.8: Standard cycle flow diagram of dairy plant

Table.7: Energy and exergy flow analysis for Standard cycle of dairy plant

Energy and exergy flows for all pipes (subsequently inlet and outlet)

Pipe no.	Total Energy flow [kW]	Therm.Mec. Energy flow [kW]	Chemical energy [kW]	Total Exergy flow [kW]	Therm.Mec. Exergy flow [kW]	Chemical exergy [kW]
1	490899.97 490899.97	490899.97 490899.97	0.00	166508.09 157013.12	166508.09 157013.12	0.00
2	315524.44 315524.44	315524.44 315524.44	0.00	7771.74 7771.74	7771.74 7771.74	0.00
3	3978.02 3978.02	3978.02 3978.02	0.00	37.11 37.11	37.11 37.11	0.00
4	4064.36 4064.36	4064.36 4064.36	0.00	102.41 77.02	102.41 77.02	0.00
5	76347.10 76347.10	76347.10 76347.10	0.00	12459.75 12459.75	12459.75 12459.75	0.00
6	76500.52 76500.52	76500.52 76500.52	0.00	12585.99 12585.99	12585.99 12585.99	0.00
7	72282.73 72282.73	72282.73 72282.73	0.00	21014.66 21014.66	21014.66 21014.66	0.00
8	317513.62 317513.62	317513.62 317513.62	0.00	5686.20 4214.04	5686.20 4214.04	0.00
9	18.97 18.97	18.97 18.97	0.00	-19.83 -19.83	-19.83 -19.83	0.00
10	5967.22 5967.22	5967.22 5967.22	0.00	4469.89 4469.89	4469.89 4469.89	0.00

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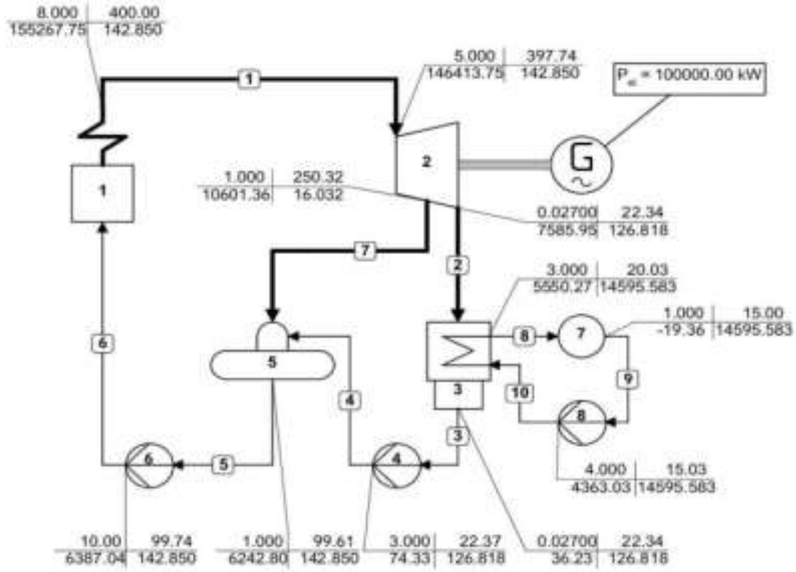

Figure. 9: Simulated flow diagaram of dairy plant

Table.8: Energy and exegry analysis for simulated cycle

Energy and exergy flows for all pipes (subsequently inlet and outlet)

Pipe no.	Total Energy flow [kW]	Therm.Mec. Energy flow [kW]	Chemical energy [kW]	Total Exergy flow [kW]	Therm.Mec. Exergy flow [kW]	Chemical exergy [kW]
1	457761.09 457761.09	457761.09 457761.09	0.00	155267.75 146413.75	155267.75 146413.75	0.00
2	307981.59 307981.59	307981.59 307981.59	0.00	7585.95 7585.95	7585.95 7585.95	0.00
3	3882.93 3882.93	3882.93 3882.93	0.00	36.23 36.23	36.23 36.23	0.00
4	3933.31 3933.31	3933.31 3933.31	0.00	74.33 49.54	74.33 49.54	0.00
5	50620.05 50620.05	50620.05 50620.05	0.00	6242.80 6242.80	6242.80 6242.80	0.00
6	50798.83 50798.83	50798.83 50798.83	0.00	6387.04 6387.04	6387.04 6387.04	0.00
7	46686.74 46686.74	46686.74 46686.74	0.00	10601.36 10601.36	10601.36 10601.36	0.00
8	309923.22 309923.22	309923.22 309923.22	0.00	5550.27 4113.30	5550.27 4113.30	0.00
9	18.52 18.52	18.52 18.52	0.00	-19.36 -19.36	-19.36 -19.36	0.00
10	5824.57 5824.57	5824.57 5824.57	0.00	4363.03 4363.03	4363.03 4363.03	0.00

4. Conclusions

Cycle-tempo software was used to simulate an energy analysis for three different steam production processes in a milk processing plant. The steam generator's boiler having the largest rate of deterioration. The greatest amount of energy was destroyed during a chemical reaction in a boiler. The boiler's exergy destruction rate was 9494 kw. Employing cycle-tempo software, the boiler exergy destruction rate is optimized (8342.5kW) by changing the boiler's input pressure. By maximizing the exergy destruction rate exergy efficiency, the exergy efficiency of the steam generation cycle can be raised. The present analysis' results largely revealed that exergy analysis might provide insightful information about the thermodynamic inefficiencies inherent in dairy processing plants. Future research in this area should focus on better understanding dairy plants and optimizing them using hybrid executive approaches like exergy economic and exergy environmental analysis to identify the most economical and environmentally friendly dairy production processes.

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