Grenze International Journal of Engineering and Technology, June Issue

Energy Conservation Opportunities for an Indian Dairy Industry

Kiran A S[1] and Dayakar G Devaru[2]
[1]Ph. D Scholar, Industrial & Production Engineering, SJCE, JSSSTU, Mysuru, Karnataka
[2]Professor, Industrial & Production Engineering, SJCE, JSSSTU, Mysuru, Karnataka
Email: kiranas@jssstuniv.in, dayakar.devaru@jssstuniv.in

***Abstract*—The milk processing industry handles large quantity of perishable liquid milk, necessitating timely processing and con-version into value-added products. This type of industry is energy-intensive, consuming substantial quantities of fuel and electricity annually leading to elevated production costs. In typical dairy plants, around 70% of energy requirements are met through thermal energy, with the remaining 30% sourced from electricity. As global awareness grows around reducing energy consumption to mitigate greenhouse gas emissions, there is an increase in focus on adopting cost-efficient energy saving measures to both reduce expenses and to contribute to environmental conservation. The main aim of this paper is to explore and suggest the best practices available in the literature and identify energy conservation measures through energy auditing to the regional diary plant. The energy and cost savings that will be obtained by implementing the best practices and energy conservation measures for thermal, electrical and renewable energy systems are evaluated and presented. This study highlights industrial best practices like pinch analysis, a well-established method in process engineering to assess energy flows and to identify areas for improvement, recover waste heat from the pasteurized hot milk to heat the incoming milk using plate type heat exchanger which reduces both process heating as well as process cooling loads and integration of solar energy for energy needs of the dairy industry. The proposed implementation cost and payback period for these recommendations are given to assist the dairy plant to initiate the implementation of energy conservation measures.**

***Keywords*— Energy Auditing, Pinch Analysis, Dairy Industry, Milk Processing, Energy Conservation Measures, Energy Efficiency.**

I. INTRODUCTION TO THE DAIRY INDUSTRY

The dairy industry is a cornerstone of global agriculture, encompassing the production, processing, and distribution of milk and milk based products that serve as essential sources of nutrition worldwide. This industry involves a complex supply chain starting with dairy farming, where cows, goats, and other ani-mals are raised for milk production. Dairy farming practices have evolved significantly, with advance-ments in animal health, nutrition, and genetics contributing to higher milk yields and more efficient re-source use. Following milk collection, the dairy industry utilizes extensive processing methods such as pasteurization, homogenization, and fermentation to create a variety of dairy products, including fresh milk, cheese, butter, yogurt, and milk powders. These products are integral to the daily diets of millions, offering vital nutrients like protein, calcium, and vitamins.

Grenze ID: 01.GIJET.11.2.721

The global dairy industry also plays a major economic role, supporting rural economies, providing em-ployment, and contributing to food security. Major dairy-producing countries include the United States, India, China, and members of the European Union, each with unique industry structures and consumer preferences. Despite its economic and nutritional significance, the industry faces numerous challenges, including environmental sustainability, fluctuating global demand, and health concerns over dairy con-sumption. Efforts to address these challenges include adopting sustainable farming practices, developing plant-based dairy alternatives, and enhancing product innovation to meet changing consumer demands. As the industry continues to evolve, the balance between production efficiency, environmental impact, and health considerations will be crucial to its long-term sustainability and contribution to global food sys-tems.
The dairy industry is a vital global sector that encompasses the production, processing, and distribution of milk and milk-based products. Dairy is an essential part of many diets, providing key nutrients such as calcium, protein, and vitamins essential for bone health, growth, and overall well-being. The industry has evolved from small-scale local production to a sophisticated global network supported by advanced tech-nologies in farming, processing, and distribution.

A. Key Components of the Dairy Industry

Milk Production: This involves dairy farming, where milk is harvested from cows, goats, sheep, and other animals. Efficient milk production relies on advanced breeding, nutrition, animal welfare, and sustainable farming practices. Many modern farms employ technology to track animal health and optimize milk yields, supporting both quality and productivity.
Processing and Packaging: Once collected, milk undergoes processing to ensure safety, extend shelf life, and produce various dairy products. Processing methods include pasteurization, sterilization, and homog-enization. Various products are created from milk, including cheese, butter, yogurt, ice cream, and pow-dered milk. Packaging plays a critical role in preserving these products and making them convenient for distribution.
Distribution and Retail: Processed dairy products are then distributed through supply chains to super-markets, local stores, and food service industries. Effective cold chain logistics are critical, as dairy prod-ucts are perishable and require refrigeration. Distribution channels vary globally, with some regions rely-ing on modern supermarkets while others use local markets.
Market Trends and Consumption: Demand for dairy products has traditionally been high in regions like North America and Europe, but consumption is rapidly increasing in Asia, particularly in China and India. In addition to traditional products, there is a growing demand for functional and organic dairy products, including lactose-free and plant-based dairy alternatives driven by health, dietary, and ethical considera-tions.
Economic and Social Impact: The dairy industry is a major employer worldwide, particularly in rural areas where dairy farming provides livelihoods for millions. It also contributes significantly to the global economy. Dairy production can boost rural economies by creating direct jobs in farming and indirect jobs in processing, logistics, and retail.

B. Challenges and Sustainability in the Dairy Industry

The dairy industry faces several challenges, including fluctuating milk prices, environmental concerns, and competition from plant-based alternatives. Emissions from dairy farming, water usage, and land man-agement have raised questions about sustainability. To address these concerns, the industry is increasingly adopting eco-friendly practices, such as reducing greenhouse gas emissions, improving waste management, and ensuring animal welfare.

C. Technological Innovations

Recent technological advancements have transformed dairy farming and processing. From precision live-stock farming to automation in milking and cooling systems, technology has enhanced productivity and sustainability. Genetic research is also used to breed cows with higher yields and disease resistance, while advanced sensors and data analytics enable farms to monitor and manage dairy herds more efficiently.

II. Literature Review

Moerkerken et. al., in their paper [1] investigates the drivers of energy efficiency in the Dutch dairy sector using a dataset of over 25,000 farm records from 2015 to 2018. It highlights three significant findings: the adoption of solar panels is the most effective measure in reducing fossil fuel use; economies of scale im-prove per-unit energy efficiency; and increased mechanization, such as the use of automatic milking sys-tems (AMS), reduces energy efficiency despite labor savings. Governmental policies promoting energy-saving measures show limited impact, emphasizing the need to focus on solar energy integration and en-hancing AMS efficiency. The study underscores the trade-offs between mechanization for productivity and sustainability goals, proposing tailored innovations in energy-efficient technologies and renewable energy utilization to align economic and environmental objectives.

Egas, D et.al., in their paper [2] examines the energy consumption and environmental impacts of nine small dairy systems in north western Spain, focusing on both agricultural and processing stages. Key findings reveal that 66% of energy use is thermal (diesel, propane, and biomass), while electricity accounts for 34%, with cold chambers being major consumption hotspots during processing. Diesel dominates in agri-cultural operations, particularly for machinery, resulting in significant greenhouse gas emissions. Suggest-ed improvements include LED lighting and energy management systems, which could cut electricity use by up to 12% and reduce emissions and costs. Additionally, adopting solar photovoltaic panels and switching to natural gas boilers are recommended for broader energy efficiency gains. The study emphasizes the unique challenges of small-scale dairies, highlighting opportunities for customized interventions to en-hance sustainability and economic feasibility.

Quijera, J. A., et.al., in their paper [3] evaluates the feasibility of integrating a solar thermal system into a dairy production facility located in northern Spain. Using the pinch analysis method, the study identifies potential energy savings by substituting natural gas with solar energy for hot water production used in pasteurization and other processes. The proposed system employs evacuated tube collectors, which are effective in the region's climate due to their ability to harness diffuse solar radiation. The analysis reveals that a solar fraction of up to 71% can be achieved, significantly reducing fossil fuel dependency and greenhouse gas emissions. Key results demonstrate that incorporating solar energy can improve the plant's energy efficiency by up to 14.1%, with optimal collector arrangements enabling substantial energy contri-butions even during low-irradiation periods. The study concludes that solar thermal integration is both technically feasible and environmentally beneficial for industrial dairy processes.

Philipp, M., et.al., in their paper [4] investigates methods to enhance energy efficiency in batch steriliza-tion processes, focusing on the whey cream sterilization process as a case study. Batch sterilization in the dairy industry often lacks direct heat recovery due to the intermittent nature of the process, leading to sig-nificant energy inefficiencies. The research proposes two innovative approaches: "Energy Storage" and "Rescheduling." The "Energy Storage" method uses thermal storage tanks to decouple energy flows, recov-ering heat during cooling phases for reuse during subsequent heating phases. This approach achieved up to 77% energy savings and reduced production time by more than half. "Rescheduling" synchronizes heating and cooling requirements between tanks to directly transfer energy, eliminating the need for thermal stor-age and achieving energy savings of up to 83%. Although "Rescheduling" is more energy-efficient, it re-quires advanced control systems and compromises flexibility in production. Both methods demonstrated favorable economics, with payback periods of less than one year, contingent on site-specific energy costs and investment scales. The results highlight that adopting these strategies can significantly improve energy efficiency, reduce greenhouse gas emissions, and lower operating costs in industrial sterilization process-es.

Ali Kaviani et.al., in their research [5] explores the use of pinch analysis to optimize energy consumption in milk powder production, a highly energy-intensive process in the dairy industry. It provides an over-view of milk drying technologies, emphasizing spray dryers as an efficient choice despite their high energy demands. The study models and evaluates four heat exchanger network scenarios using the Aspen Energy Analyser (AEA) software to identify the optimal configuration for energy recovery. The best-performing network, MER-3, demonstrated the lowest total cost, reduced heating and cooling demands, and minimized the number of heat exchangers, although it required a slightly larger surface area compared to some other configurations. The findings highlight the potential to achieve substantial energy savings by implementing advanced heat recovery strategies, demonstrating the importance of integrating thermal management and cost optimization techniques in dairy industry processes. The study concludes with a recommendation for further optimization using combined exergy and pinch analysis.

P Panneerselvam et.al., in their study [6] investigates energy conservation strategies for dairy plants by optimizing the use of waste heat in vapour compression refrigeration systems. Dairy operations rely on energy-intensive processes for cooling milk and heating water, typically using separate systems for these functions. The research identifies an opportunity to recover waste heat from the ammonia refrigerant in the vapour compression cycle, which reaches temperatures around 120°C. The proposed solution involves installing a double-pipe heat exchanger to transfer this untapped heat to water, producing hot water or steam for dairy operations. This integration reduces reliance on traditional wood-fired boilers, cutting fuel costs and enhancing energy efficiency. The study emphasizes that adopting such heat recovery systems can save 20–60% of the energy used for cooling

milk while also generating sufficient hot water for clean-ing and other processes. It further highlights the economic and environmental benefits of incorporating these systems, including reduced energy costs and fossil fuel dependence.
The best practices in the above literature is analyzed and used for bench marking with the Mega Dairy plant along with the energy audit carried out.

III. Material and Methods: Existing Manufacturing Process:

A. Equipment List

TABLE I: LIST OF MAJOR EQUIPMENT USED IN MEGA DAIRY PLANT WITH THEIR RATINGS

Sl. No.	Equipment	Qty	Rating
1.	Air Compressor	4	79kw
	REFRIGERATION SECTION		
2.	Screw Compressor	3	262kw
3.	Vilter compressor motor	2	45kw
4.	Chilling Water pump motor	4	15kw
5.	Motor (condenser 1 fan), 15hp	03	11 kw
6.	VFD for Screw Compressor	03	250 kw
	ETP		
7.	Air Blower motor	2	30 kw
8.	Intermediate motor	2	7.5 kw
9.	Sludge Sump motor	2	11 kw
10.	Treated water pump motor	1	11 kw
	WTP		
11.	Hydro soft pump Motor	03	11 kw
12.	Hydro filter pump Motor	02	7.5 kw
13.	Hydro RO pump Motor	03	11 kw
14.	RO High pressure pump	02	15 kw
15.	Filter feed pump	02	11 kw
	MILK RECEPTION		
16.	Tanker Unloading Pump Motor	02	7.5 kw
	CIP SECTION		
17.	CIP Tanker Line	03	7.5 kw
	PROCESS CIP		
18.	Line -1	03	11 kw
	MILK PROCESSING		
19.	Cream Separator motor 20KL	01	37 kw
20.	Cream Separator motor 30 KL	01	25 kw
21.	30KL Homogenizer		200 kw
22.	20KL Homogenizer		132 kw
23.	Booster motor pump milk	02	11 kw
	PMST		
24.	PMST to Product Section	03	7.5 kw
	BUTTER SECTION		
25.	CBMM Motor 3Ø	03	11 kw
	BOILER		
26.	VFD for ID Fan Boiler	02	55 kw
	Fuel handling system		
27.	Fan DE dusting	01	7.5 kw
	Boiler operating system		
28.	Feed pump	02	7.5 kw
29.	Primary Forced draft fan back ward type	01	11 kw
30.	Secondary Forced draft fan back ward type	01	9.3 kw
31.	Wood Crushing motor.	01	75 kw
32.	Induced Draft Fan	01	55 kw
33.	Crusher Motor,	01	7.5 kw
34.	Feed Water Pump	01	7.5 kw
	OLD Boiler		
35.	ID Fan motor.	01	15 kw
	PRODUCT		
36.	**Ghee Separator motor**	01	7.5kw

Table 1 shows the list of major equipment used in dairy industry with their ratings and quantity.

B. Milk Processing System

In the dairy industry, raw milk undergoes (Figure 1) various processes to produce consumable milk and milk products. These include chilling, standardization, homogenization, pasteurization, separation, and packaging. Efficient handling, storage, and cleaning are critical to ensure product quality and hygiene.

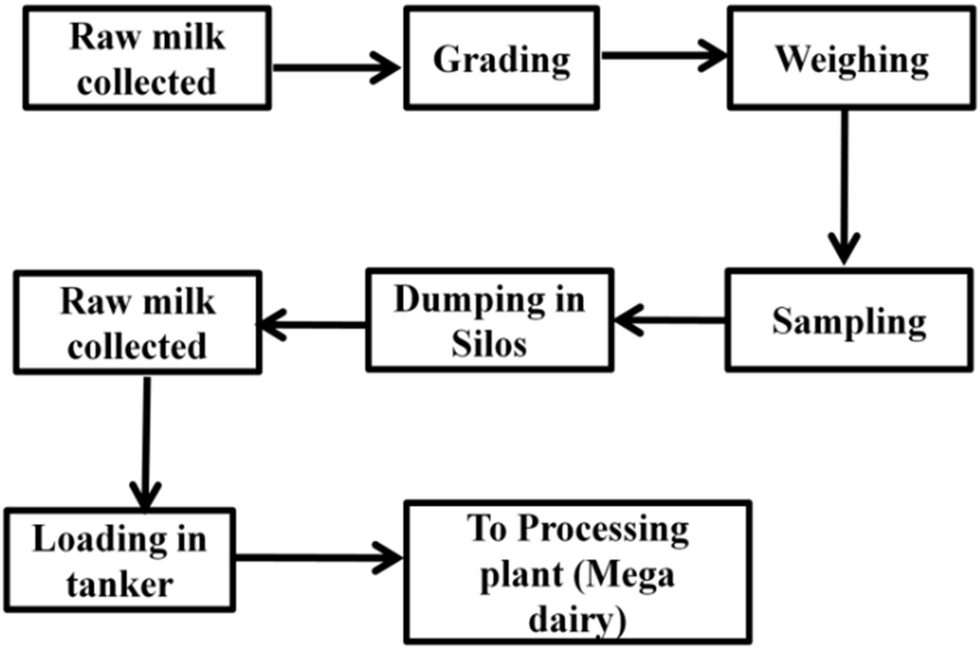

Figure 1: Process flow diagram of milk reception section.

C. Key Processes in Milk Processing

Milk Reception and Storage:

- Milk is collected from rural villages and delivered to processing plants via milk cans and tankers.
- Chilling centres preserve milk at 4–7°C using Bulk Milk Coolers (BMCs).
- Milk undergoes quality control tests for fat, SNF (Solids Not Fat), and acidity before storage in SILO tanks (capacity: 100,000 litres each).

Standardization and Pasteurization (Figure 2):

- Milk is heated to 78°C and cooled to 6°C to eliminate microbial growth.
- Pasteurized milk is tested for fat, SNF and acidity. If standards are met, it is stored in Horizontal Milk Storage Tanks (HMST) at 5–7°C.
- Pasteurizers use plate heat exchangers to optimize energy transfer.

Separation into Skim and Cream Milk (Figure 3):

- Pasteurized milk is separated into skim milk (3% fat, 8.5% SNF) and cream milk.
- Cream undergoes additional pasteurization (heated to 82°C, cooled to 10–11°C).
- Skim milk is used to produce toned or double-toned milk.

Milk Product Manufacturing:

- Products include toned milk, curd, butter, ghee, lassi, peda, and flavored milk. High-fat products like butter and ghee involve further processing of cream

Cleaning-in-Place (CIP) System

CIP systems ensure hygiene by cleaning equipment without dismantling.
Cleaning steps:

- Water rinse to remove residues.
- Sodium hydroxide removes fat deposits.

- Nitric acid eliminates milk scale.
- Hot water circulation (80°C) sterilizes equipment.
- Fresh water rinse brings equipment to room temperature.

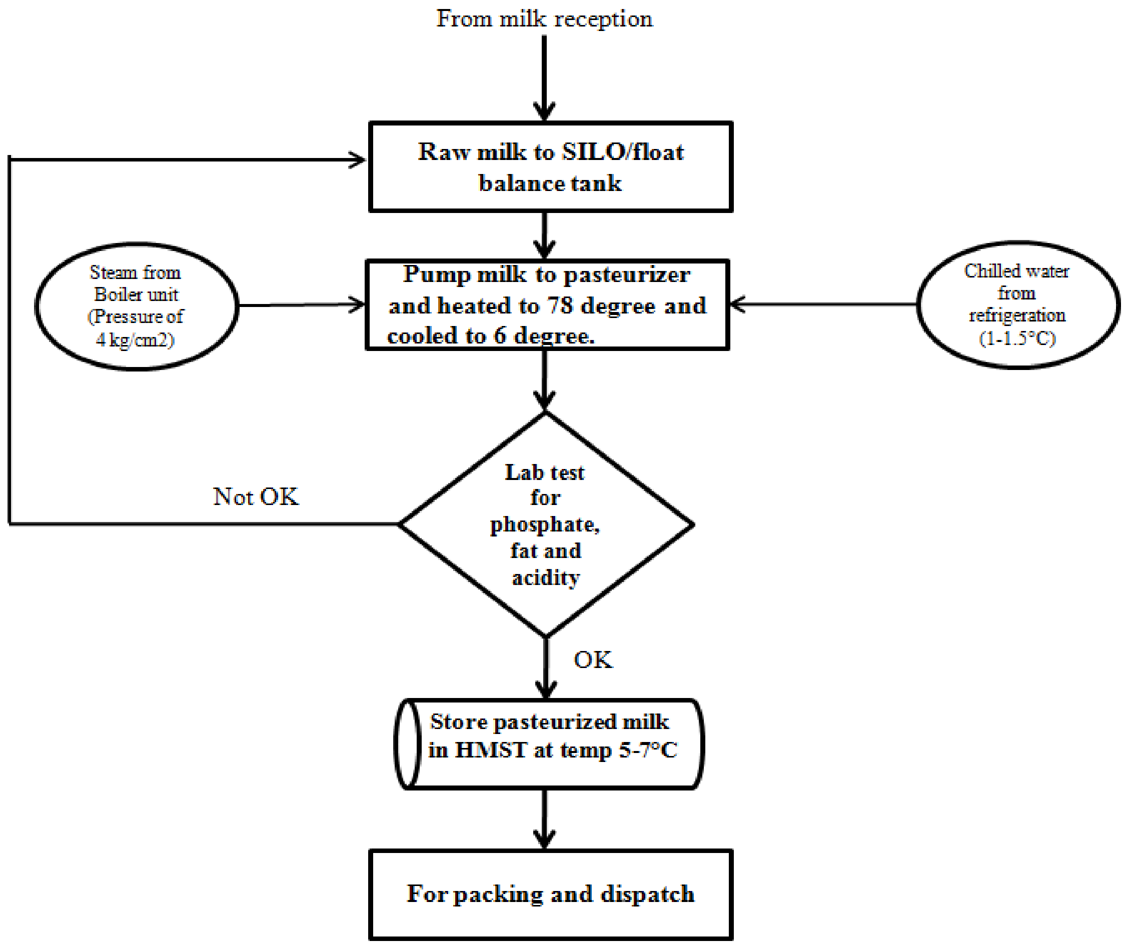

Figure 2: Process flow diagram of milk pasteurization section.

Packaging and Cold Storage

Packaging

- Automated machines pack milk and milk products in various volumes (500 ml, 1000 ml) at speeds of 1500 to 1700 packets/hour.
- Packed products are sent to cold storage.

Cold Storage

- Facilities maintain temperatures at 1 to 3°C using ammonia as a refrigerant.
- Products are stored in designated rooms for milk and dairy derivatives, preventing contamination and ensuring longevity.

IV. Energy Utilization in Existing Dairy Processing Industry

Electrical energy consumption by the plant is shown in Table 2.
The contract demand of the company is 2,000 kVA and they are getting charged for 85% of this contract demand i.e., 1,700 kVA at the rate of Rs. 265/kVA every month.
The power factor is 1 and they are not charged any penalty for it. Fuel consumption by the boiler is shown in Table 3.
Electricity is a significant expenditure for operating motors, fans, pumps, HVAC, and refrigeration systems. Energy-efficient practices include optimizing process cooling and cold storage operations.

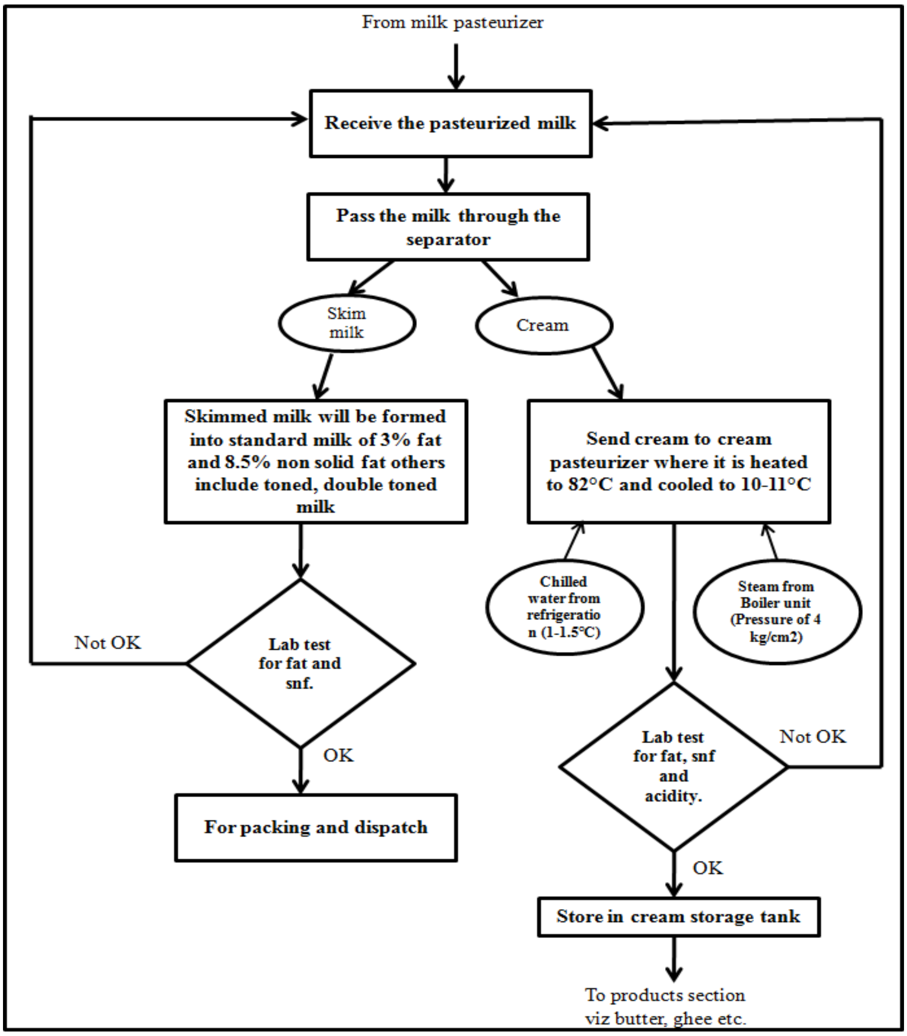

Figure 3: Flow chart depicting the Separation of pasteurized milk into skim milk and cream milk

TABLE II: ENERGY CONSUMPTION DATA FROM SEPTEMBER 2022 TO AUGUST 2023

Sl. No.	Month	Total Consumption in KWh	Metered Demand kVA	kWh Charges	kVA Charges	Fuel Adjustment Charges	Tax	Payable Amt in Rs.
1	Sep-22	5,38,700	1,220	40,69,120	4,50,500	2,85,511	3,66,221	51,58,560
2	Oct-22	5,36,600	1,160	40,53,160	4,50,500	2,84,398	3,64,784	51,52,842
3	Nov-22	5,09,300	1,190	38,45,680	4,50,500	2,69,929	3,46,111	48,99,338
4	Dec-22	5,17,100	1,150	39,04,960	4,50,500	2,74,063	3,50,123	49,52,698
5	Jan-22	5,24,800	1,290	39,63,480	4,50,500	2,78,144	3,56,038	50,28,250
6	Feb-23	4,99,200	1,310	37,68,920	4,50,500	2,64,576	3,39,095	48,09,321
7	Mar-23	5,76,700	1,350	43,57,920	4,50,500	3,05,651	3,91,781	55,13,622
8	Apr-23	5,78,500	1,370	43,71,600	4,50,500	3,06,605	3,93,561	52,09,509
9	May-23	6,12,100	1,410	45,29,540	5,95,000	14,81,282	4,07,884	70,85,265
10	Jun-23	5,84,955	1,340	43,28,667	5,95,000	2,86,628	3,89,175	55,77,275
11	Jul-23	5,90,939	1,360	43,72,949	5,95,000	6,20,486	3,93,565	59,68,071
12	Aug-23	6,12,969	1,410	45,35,971	5,95,000	8,27,508	4,08,237	63,51,886
Total / Avg		66,81,863	1,297	5,01,01,967	59,84,000	54,84,781	45,06,575	6,57,06,637

Amount paid / kWh = (Total kWh Charges + Total Fuel Adjustment Charges) / Total kWh Consumption * Tax %

= (5,01,01,967 + 54,84,781) / 66,81,863 * 1.07%

= ₹ 8.90

TABLE III: FUEL CONSUMPTION BY THE BOILER PER YEAR

Fuel Used	Calorific Value	Usage per day	Usage per Year	Cost per kg	Cost per year
Wood / Briquettes	3,000 kCal/kg	16 tons	5,840 tons	₹ 7/kg	₹ 4,08,80,000

V. RESULTS AND DISCUSSION: ENERGY CONSERVATIONS OPPORTUNITIES

The Mega Dairy Plant equipped with advanced technologies, demonstrates commendable sustainability practices, including biogas generation and solid waste management. However, additional energy-saving measures are proposed.
Key opportunities identified include:

A. Deployment of Rainwater Harvesting System

Existing Water Source: Currently, the Mega Dairy plant relies on two bore wells located within its premises and municipality water to meet its water requirements.

Proposed Rainwater Harvesting (RWH) System
Rainwater harvesting is proposed to supplement the water supply and recharge groundwater.
The system will focus on rooftop harvesting and redirection of rainwater.
Rainwater collected from the rooftops of the main process plant can be directed to the ground and subsequently to sump.
The water in the sump can be channelized to recharge wells for groundwater replenishment.
Average annual rainfall in Mysuru city is 1,100 mm
Area of roof = 11,460 sq. m.
Height of the rainfall = 1.1 m
Volume of rainfall over the roof = Area of roof x height of rainfall = 11,460 * 1.1 = 12,606 m3 or 1,26,06,000 liters.
Assuming that only 90 per cent of the total rainfall is effectively harvested
Volume of water that can be harvested = 1,19,75,700 liters (1,26,06,000 liters x 0.95) per year.
Cost Savings = 1,19,75,700 liters x Rs. 31.2 / 1000 liters = Rs. 3,73,641 per year
Implementation Cost = Rs. 10,000 / 100 Sq.m. x 11,460 Sq.m = 11,46,000
Simple Payback = 11,46,000 / 3,73,641 = 3.06 years or 3 years 1 months

B. Deployment of Solar Water Heating System

The installation of a properly maintained solar water heating system with a capacity of 50,000 liters/day can generate hot water at 70ºC, that can be used as preheated feed water to the boiler using solar energy.

Modifications Required
Minor changes in the pipeline arrangement for feed water. Installation of solar panels and integration of a hot water storage tank with the existing system.
Heat Energy Saved: Providing a solar water heater (50,000 liters capacity, heating water from ambi-ent temperature 27ºC to 70ºC) can save 21,50,000 kCal/day.

Fuel Savings
Fuel Type: Wood
Calorific Value: 3,000 kCal/kg
With a boiler efficiency of 80%, fuel savings are estimated as = 21,50,000/3,000 = 716 kgs/day
Annual Fuel Savings = 716 x 365 = 2,61,340 kgs/yr or 784,020 MJ
Cost of fuel: ₹7/kg.
Fuel cost savings = 716 kg/day x 365 days/yr x Rs. 7/kg = Rs. 18,29,380 /year.
Installation cost of solar heating system, insulated storage tank, pipelines, and associated insulation: Rs. 37,50,000
Simple payback period = 37,50,000 / 18,29,380 = 2.05 years = 2 years 1 months.

C. Deployment of Rooftop Solar PV System

The existing rooftop space above various units in the plant can be utilized for the installation of Solar PV panels for electricity generation. The approximate total built-up area available for rooftop installation in the various units is shown in Table 3 below:

TABLE IV: DETAILS OF BUILT-UP AREA AT MEGA DAIRY

Sl. No.	Block	Area (Sq. m)
1.	Main Plant	11,460
2.	Utility	2,375
3.	Admin	800
4.	Canteen	711
5.	Weigh Bridge	155
6.	Time Office	275
7.	Tanker Bay	666
Total		16,442

Solar PV Installation Potential: Considering rooftop solar installation for 75% of the available built-up area, approximately 12,000 sq.m is feasible for installation.

Based on the thumb rule that 100 sq.ft (9.2–10 sq.m) of shade-free roof area is required per kW of solar PV capacity, the total potential rooftop solar PV capacity is approximately 1,200 kW. Also, there contract demand is 2,000 kVA which is well above the proposed rooftop solar PV capacity.

Economic Analysis: Average Solar Irradiation in Karnataka: 1,266.52 W/sq.m

Generation Potential: 1 kWp solar rooftop plant generates on average 5.0 kWh/day (based on 5.5 sunshine hours, as per MNRE calculator) [7].

Total Annual Units Generated: 5 kWh / day x 1200 kW x 300 solar days/year = 18,00,000 units / annum.

Average Electricity Cost: Rs. 8.9/kWh

Expected Cost Savings: Rs/annum = 18,00,000 x 8.9 = 1,60,20,000 / annum.

Investment Cost:

Rs.80,000/kW (including battery, inverter, and accessories; excluding MNRE subsidy).

Total investment for 1200 kW = Rs.9,60,00,000.

Simple payback period = 9,60,00,000 / 1,60,20,000 = 6 years

D. Regenerative heating and cooling

Pinch Analysis

This technique is widely used in industries with energy-intensive processes, such as chemicals, oil refin-ing, and food production, offering significant cost savings and environmental benefits. Pinch technology supports the design of heat exchanger networks and retrofitting of existing systems, ensuring that energy efficiency is maximized while maintaining process constraints and product quality.

Beyond energy, it can also address water and material integration, making it a versatile tool for sustainable industrial operations. Its application is increasingly critical in achieving energy efficiency targets and reducing greenhouse gas emissions, aligning with global sustainability goals.

Pinch analysis is a systematic method for optimizing energy efficiency in industrial processes by examin-ing the flow of heat energy within a system. The primary goal of pinch analysis is to minimize the need for external energy inputs by maximizing heat recovery between process streams.

At its core, the method identifies the "pinch point," a critical temperature in the system where the minimum allowable tempera-ture difference (ΔTmin) occurs. This point acts as a barrier, separating areas where heat can be efficiently transferred between hot and cold streams.

The analysis begins with constructing composite curves, which are graphical representations of the cumu-lative heat capacities of all process streams plotted against temperature.

These curves highlight the energy requirements and potential for heat recovery in the system. The overlap between hot and cold streams in these curves indicates areas where heat exchange is possible as shown in Figure By designing or modi-fying heat exchanger networks based on the pinch point, industries can achieve significant energy sav-ings, often reducing energy consumption by 20–40% [8].

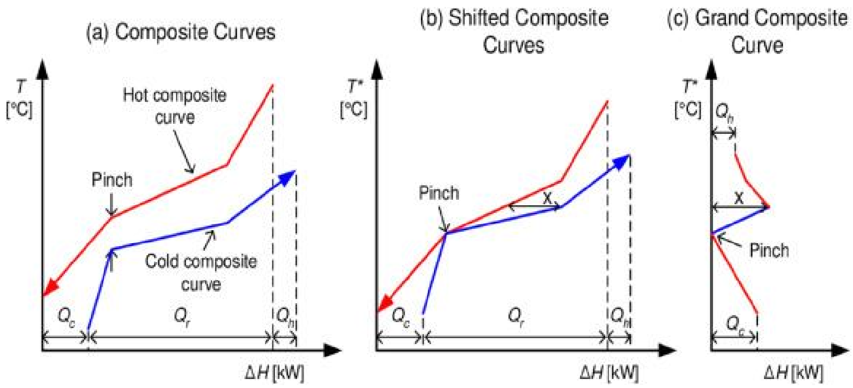

Figure 4: Pinch Analysis [9]

The above figure represents pinch technology in the dairy industry:

- Hot Composite Curve (Dark Red): Represents heat release during processes like milk pasteuriza-tion, a critical step in dairies.
- Cold Composite Curve (Dark Blue): Represents heat absorption during processes like chilling and pre-cooling of milk, which are vital in the Indian climate to prevent spoilage.
- Pinch Point: Indicates the energy recovery potential, where optimized heat exchange can mini-mize external energy needs.

Energy Savings Potential

Energy savings that can be achieved by designing plate heat exchanger as per the pinch analysis is given as follows.

Energy Consumption for Pasteurization = Energy consumed by the boiler per year x Percentage utilized for Pasteurization

= 480 tonnes wood / month x 12 months / yr x 12.552 MJ / tonne x 30 %

= 21,690 MJ /yr

Using of plate heat exchanger (Figure 5) to transfer the heat from pasteurized milk to incoming new batch of milk can save up to 40 % of heat required for pasteurization and conservatively estimating that a sav-ings of 20 % can be achieved, the saving calculations are given as follows.

Energy Savings = Energy consumed in MJ / yr x 20 %

= 21,690 MJ /yr x 20 %

= 4,338 MJ /yr

Energy Cost Savings = (4,338 MJ /yr / 12.552 MJ / tonne) x Rs. 7,000 / tonne

= ₹ 2,419,216 / yr

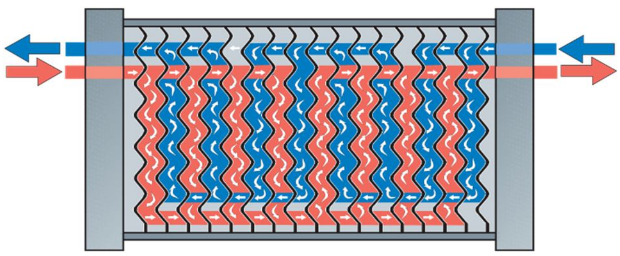
Figure 5: Plate Heat Exchanger used in Dairy Industry [8]

The implementation cost for the plate heat exchanger is estimated to be around Rs. 40,00,000 for exchang-ing the heat of 4,00,000 liters of milk produced per day. The simple payback period is calculated as,

Simple Payback = Implementation Cost / Energy Cost Savings

= 40,00,000 / 2,419,216

= 1.65 years or 1 year 8 months

Hence, by installing plate heat exchangers based on pinch analysis technique to exchange the heat of pas-teurized milk with the incoming milk, energy savings of 4,338 MJ and energy cost savings of Rs. 2,419,216 can be achieved. This energy conservation measure has an implementation cost of Rs. 40,00,000 with a simple payback of 1 year 8 months.

E. Install FRP blade on Cooling Tower Fan

Cooling towers play a pivotal role in the dairy industry, ensuring that production processes like pasteuri-zation, milk cooling, and refrigeration operate efficiently. Metallic blades, though durable, are susceptible to corrosion, increased weight-induced stress, and inefficiencies. Replacing them with FRP blades offers significant operational advantages like durability and corrosion resistance. light weight design, improved aerodynamic efficiency, noise reduction, maintenance and longevity.

Energy savings potential

Energy Consumption fans = Motor Rating of the fan x Number of fans x hours of usage x Load factor / Efficiency

= 5 hp x 0.746 kW/hp x 9 x 8,760 hrs/ yr x 0.8 / 80 %

= 294,073 kWh /yr

Lighter FRP bladed fans consume approximately 15% [10] lesser energy when compared to conventional metallic bladed fans and the saving calculations are given as follows.

Energy Savings = Energy consumed in kWh / yr x 15 %

= 294.073 kWh /yr x 0.15

= 44,111 kWh / yr

Energy Cost Savings = Energy savings in kWh / yr x Cost paid / kWh

= 44,111 kWh /yr x ₹ 8.9 / kWh

= ₹ 392,588 / yr

The implementation cost for the plate heat exchanger is estimated to be around Rs. 12,000 per fan and hence the total implementation cost will be Rs, 1,08,000. The simple payback period is calculated as,

Simple Payback = Implementation Cost / Energy Cost Savings

= 1,08,000 / 392,588

= 0.28 years or 4 months

Hence, by installing FRP blade on Cooling Tower Fan, energy savings of 44,111 kWh / yr and energy cost savings of Rs. 392,588 / yr can be achieved. This energy conservation measure has an implementation cost of Rs.1,08,000 with a simple payback of 4 months.

TABLE V: KEY RECOMMENDATIONS SUMMARY

Sl. No.	Proposal	Energy Savings per year	Cost Savings per year	Investment (₹)	Payback Period (yrs)
1	Rainwater Harvesting	1,19,75,700 liters	3,73,641	11,46,000	3.06
2	Solar Water Heating System	7,84,020 MJ	18,29,380	37,50,000	2.05
3	Rooftop Solar PV System	18,00,000 kWh	1,60,20,000	9,60,00,000	6
4	Regenerative heating and cooling	4,338 MJ	24,19,216	40,00,000	1.65
5	Install FRP blade on Cooling Tower Fan	44,111 kWh	3,92,588	1,08,000	0.28
	Total	**-**	**2,10,34,825**	**10,50,04,000**	**5**

Key recommendations summary is shown in Table 4.

The total energy used is 66,81,863 kWh/yr and 5,840 tons of wood. Total energy costs for this period was ₹ 10,65,86,637/-. The Energy Conservation Opportunities (ECOs) contained in this Report could save 7,88,358 MJ, 18,44,111 kWh/yr and 1,19,75,700 liters. This will result in reduction of CO2 emissions of 15,12,644 Kgs or equal to planting 72,030 Trees. The total energy cost savings would amount to approxi-mately ₹ 2,10,34,825/- or approximately 20% of the annual energy costs for this facility. The total esti-mated implementation cost is ₹ 10,50,04,000/- which gives an average simple payback of around 5 years.

Additional recommendations which will not give significant energy savings are listed as follows. These measures are aimed at improving energy efficiency and modernizing processes under the Cluster Devel-opment Program. These include advancements in both Electrical Systems and Thermal Systems as outlined below:

- Installation of occupancy sensors
- Use of Energy-efficient motors
- Ammonia Compressor Motor Optimization: Install soft starters with energy-saving functionalities for improved efficiency during low load conditions, such as when only one or two cylinders are active.
- Condenser Water Pump Improvement: Enhance pump performance and reduce energy losses by applying glass flake coating to pump impellers and casings.
- Advanced Pouch Filling Machines: Replace pneumatic pouch filling machines with PLC-based mechanical pouch filling systems to achieve substantial energy savings and operational efficien-cy.

- Thermal Energy Storage System: Replace conventional Ice Bank Tank (IBT) systems with Thermal Energy Storage (TES) systems to enhance energy efficiency and load balancing.
- Improved Processes for Dairy Products: Modernize the production processes for items like paneer and ghee to minimize energy wastage.

VI. CONCLUSION

The study systematically explores energy conservation measures for the Indian dairy industry, emphasizing the im-portance of energy efficiency to reduce costs and environmental impact. Key recommendations include the adoption of advanced technologies such as pinch analysis for energy flow optimization, integration of solar energy systems, and the recovery of waste heat using innovative heat exchange systems. These strategies demonstrate significant potential for reducing energy consumption in both thermal and electrical domains, with actionable insights for immediate and long-term implementation. The financial analyses provided, including payback periods for solar water heating systems and rooftop solar PV installations, underscore the economic viability of these measures. The conclusion highlights the broad-er implications of energy-efficient practices in achieving sustainability goals, reducing greenhouse gas emissions, and fostering a more cost-effective dairy industry in India. This paper advocates for industry-wide adoption of these measures to balance economic performance with environmental stewardship effectively.

REFERENCES

[1] Albert Moerkerken , Sem Duijndam , Julia Blasch , Pieter van Beukering , Arnoud Smit Determinants of energy efficiency in the Dutch dairy sector: dilemmas for sustainability Journal of Cleaner Production 293 (2021) 126095, doi:10.1016/j.jclepro.2021.126095

[2] Egas, D, Ponsa, S., Llenas L, & Colón, J. (2021). Towards energy-efficient small dairy production systems: An environmental and economic assessment. Sustainable Production and Consumption, 28, 39–51. doi:10.1016/j.spc.2021.03.021.

[3] Quijera, J. A., Alriols, M. G., & Labidi, J. (2011). Integration of a solar thermal system in a dairy process. Renewable Energy, 36(6), 1843–1853. doi:10.1016/j.renene.2010.11.029.

[4] Philipp, M., Schumm, G., Heck, P., Schlosser, F., Peesel, R.-H., Walmsley, T. G., & Atkins, M. J. (2018). Increasing Energy Efficiency of Milk Product Batch Sterilisation Energy. doi:10.1016/j.energy.2018.09.002.

[5] Ali Kaviani, Alireza Aslani , Rahim Zahedi, Hossein Ahmadi, Mohammad Reza Malekli, "A new approach for energy optimization in dairy industry", Cleaner Engineering and Technology 8 (2022) 100498.

[6] P Panneerselvam, M R Subbarayan, E Murugan and E Subramaniyan, "Energy Conservation Through Effective Utilization of Vapour Compressor System In Dairy Plant", International Journal of Mechanical Engineering and Robotics Research, ISSN 2278 – 0149 , Vol. 3, No. 2, April 2014.

[7] Ministry of New and Renewable Energy. (n.d.). Rooftop solar calculator. https://solarrooftop.gov.in/rooftop_calculator

[8] Dairy processing Handbook, The Tetra Pak Group, https://dairyprocessinghandbook.tetrapak.com/chapter/heat-exchangers (accessed on 25/12/2024)

[9] Ali Kaviani, Alireza Aslani, Rahim Zahedi, Hossein Ahmadi, Mohammad Reza Malekli, "A new approach for energy optimization in dairy industry", Cleaner Engineering and Technology, Volume 8, June 2022, 100498 https://doi.org/10.1016/j.clet.2022.100498

[10] Promoting Energy Efficiency and renewable Energy in selected MSME in India, https://sidhiee.beeindia.gov.in/pdf/case-studies/6.pdf