International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 8, ISSN No. 2455-2143, Pages 160-165
Published Online December 2022 in IJEAST (http://www.ijeast.com)

THERMAL ENERGY CONSUMPTION DURING MILK PROCESSING IN A COMMERCIAL DAIRY PLANT: A CASE STUDY

Subhash Prasad
Assistant professor
Dairy Engineering Department
College of Dairy Science, Kamdhenu University
Amreli, Gujarat, India

Abstract---**Energy is important component of dairy industry. Dairy industry processing mainly based on heat transfer that's required thermal energy. Thermal energy conservation in dairy plant means to develop a methodology to achieve energy saving to reduce energy costs in processing system. The aim of this study was to investigate consumption of thermal energy of market milk and dairy product per tone of product. The data was analyzed of a commercial dairy plant in January to march 2021.In dairy processing plant, steam was utilized in milk pasteurization, cream pasteurization, butter processing, ghee making, dahi making, butter milk thermization were found as 16.70, 26.60, 47.22, 540.0, 72.50 & 59.90 kg per 1000 kg product, respectively and corresponding thermal energy were45.1, 71.8, 127.9, 1458.0, 195.8 and 161.7 MJ per 1000 kg product processing. The average steam consumption of crate washing was reported as 84.3 kg steam per 1000 crate. The average refrigeration load requirement of dairy plant was found 172.9 TR and corresponding running cost of refrigeration unit was found Rs. 14.25 per TR per hour. The data of this case study was compared with previous study in interpretation of those results.**

Keywords---**Dairy plant, Refrigeration load, Utilities, Pasteurization, Thermization, Thermal energy.**

I. INTRODUCTION

Energy is the most important element for economic development as its optimized use has become as burning issue of International importance [1].Milk processing is an energy-intensive process, requiring fossil fuel combustion for production purposes, leading to greenhouse gas emissions [2]. The dairy industry uses a variety of energy sources, including steam, hot water, compressed air, chilled water, and electricity. Dairies must focus on maintaining high product quality while simultaneously lowering production costs. These requirements can be met through energy conservation investments, which can include the purchase of energy-saving technologies and the implementation of plant-wide energy conservation practices. As the milk processing industries extend their production horizons the energy consumption in these and the upcoming industries will tend to rise. Dairy and other food processing industry use a high amount of energy in processing, manufacture and storage of various products due to obsolete technology [3]. Energy in dairy plants directly refers to the utility's generation and consumption such as steam, refrigeration, electricity, air and water [4]. Water and steam are used as heat transferring medium in dairy operations. Water consumption is very high in most of the dairy operations [5] and [6].The dairy industry is divided into sections such as raw milk reception, processing, products, storage, and dispatch. It is estimated that one-third of the energy consumed by the dairy industry is used in processing operations, and the refrigeration plant accounts for 50-60% of total electrical consumption because average refrigeration requires the most energy [7]. To run the plant economically and efficiently, accurate data on utility consumption must be available for examining and then improving energy consumption because an increase in energy consumption is also due to inefficient use of dairy equipment [8].

A methodology has been proposed by [9] and instrumentation described by [10] to conduct energy audits in food plants such as dairy and meat processing. The procedure includes monitoring of energy consumption and mass flow of food materials during regular plant operation. The method was used to measure the ratio of energy to mass of product for fluid milk and other Dairy Products.

The work was carried out and data collection in three day in a commercial dairy plant in a Gujarat during the month of January to march 2021. Data analyzed in the department of college of dairy science, Amreli, Gujarat.

II. MATERIALS AND METHODS

(A) Plant Detail --The plant is mainly engaged in the processing of fluid milk (180000 lit./day), which is marketed under depending upon the fat content viz. Gold, tazza, chai mazza , SNT and T-Special. Apart from these,

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 8, ISSN No. 2455-2143, Pages 160-165
Published Online December 2022 in IJEAST (http://www.ijeast.com)

Plant also manufactures ghee (approx. 3000 kg per day), dahi (approx. 4000 kg per day), and butter milk (approx. 30,000 lit. per day).

(B)Measuring Techniques---

Temperature, pressure and flow measurement---The energy consumed in the various dairy operations was evaluated by measuring the different parameters like temperature, pressure, flow measurement and steam measurement. Temperature and pressure was measured by thermometer and pressure gauge respectably already connected with the particular equipment and pipeline. Flow measurement is an important parameter for the calculation of milk, cold water and steam for the various sections. Tank level methods were used to determine the flow rate of milk, cold and hot water. The change in the level of the tank was noted in a given time. The mass flow rate was calculated from tank diameter or cross sectional area and density.

Steam flow rate was calculated by the following equation [11].

$$\mathbf{Ws} = \frac{\mathbf{Wp.Cp(T2-T1)}}{\mathbf{Hs-Cpc.T2}} \text{---------- --- (1)}$$

Where, Ws is the steam flow rate (kg/h), Wpis water or product flow rate (kg/h), Cp is the specific heat of water or product, (kJ/kg°C), T_1 is the initial temperature of hot or product (°C), T_2 is final temperature heated water or product, H_s is enthalpy of steam at an injection pressure (kJ/kg), Cpc is the specific heat of condensate (kJ/kg°C).

(C)Calculation methods---Calculation of utilities like water, steam, refrigerant heat consumption in various sections and equipments are discussed below.

Water---Water is mostly used for cleaning purposes like cleaning of equipments, storage tanks, cans, crates etc. in the various sections. The consumed water was calculated by multiplying the water flow rate and time required for cleaning.

(D) Steam consumption in processing of milk and milk products:

Milk and cream processing--The steam consumption per day was noted by the flow meter. Daily milk processed and cream pasteurized were noted by the flow meter and also checked by scale provided inside the silos/tanks.

Butter, Ghee and Dahi production--The steam consumption per day was noted by the flow meter. Daily amount of butter, ghee and butter making were noted by the flow meter.

(E)Regeneration efficiency (R) of PHE pasteurizer--Milk was pasteurizing in plate heat exchanger. The pasteurizer consists of 1st regeneration, 2nd regeneration, final heating section, holding section; steam/ hot water section and chilling section. First all the temperature measuring probes fixed at various section of pasteurizer were checked for their accuracy by comparing them with standard digital thermometer. Pressure gauge was fixed in steam line coming to pasteurizer. Regeneration efficiency (R) was calculated by using the following formula:

$$\mathbf{R}=\frac{\mathbf{(tr-ti)x\ 100}}{\mathbf{(tp-ti)}} \text{---------- ----------(2)}$$

Where,

t_r=Temperature of milk coming out of regeneration section and entering heating section (°C), t_i = Raw milk temperature (°C), t_p = Temperature of pasteurized milk (°C).

Pasteurizer capacity was calculated by measuring the flow meter and also checks by measuring the change in milk level in silo per unit time. Nowadays, pasteurization consumes only a slight amount of energy, regeneration efficiency between 90%and 94% is regarded as optimal [12].

(F) Refrigeration load:

Chilling of raw milk and pasteurized milk by using chilled water and the refrigeration load are calculated by:

$$\mathbf{Q}=\frac{\mathbf{Mc\ .Cp\ (T2-T1).f}}{\mathbf{1000}} \text{----------(3)}$$

Where,

Q is refrigeration load (MJ/kg), Mcis chilled water mass flow rate (kg/h), Cp is the specific heat of chilled water, T_1 is the initial temperature of chilled water (^oC), T_2= final temperature of chilled water (^oC) and f is a factor which relates the heat loss in the chilled water pipeline while conveying it from the chilled water tank to the equipment (the value is taken as 1.1)

III. RESULTS AND DISCUSSIONS

The results of the study carried out for the consumption of water, steam and refrigeration in the processing of market milk, cream, butter, ghee, Dahi, butter milk in a commercial dairy dairy plant are presented and discussed.

(A) Water consumption:

In dairy plant water consumption in different processing operations and sections such as cleaning purpose and processing section was calculated and discussed separately. The calculated value and major findings of water consumption has been presented in Table 1. Maximum water consumption was found in case of CIP. The total water consumption in day-1, day-2 & day-3 were 2, 68, 271(l/day); 2,74,296 (l/day) and 2,76,480 (l/day) respectively. Average water consumption of dairy plant was found 2, 73,016 litres per day.

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 8, ISSN No. 2455-2143, Pages 160-165
Published Online December 2022 in IJEAST (http://www.ijeast.com)

Table-- 1: Water consumption (l/day)

S.N.	Section	Day-1	Day-2	Day-3	Average
1	**Reception**	24,472	30,912	26,519	27,301
2	**Butter Making**	140	238	273	217
3	**Process hall**	1,1270	13,432	13,731	12,811
4	**CIP**	1,63,248	1,54,128	1,64,496	1,60,624
5	**Curd and butter milk**	16,238	11,063	13,685	13,662
6	**Crate washing and filling**	22,120	30,156	25,487	25,921
7	**Other section and losses**	30,784	34,367	32,289	32,480
Total Water Consumption		2,68,271	2,74,296	2,76,480	2,73,016

(B) Steam Consumptions:
The largest share of fuel consumed by the dairy industry is used for direct process heating and steam generation via boiler systems. Daily steam consumption (kg) and corresponding thermal energy (GJ) of different sections in dairy plant shown in Table 2. Average steam pressure was found 2.4 Kg_f /cm^2. One kilogram of steam at 2.4 Kg_f /cm^2 consist 2.7 MJ thermal energy. Daily average steam consumption (kg) and corresponding thermal energy (GJ) were found 10,797 kg steam and 29.15 GJ respectively in commercial dairy plant. Daily steam consumption (kg) and corresponding thermal energy (GJ) of different sections in dairy plant. Maximum thermal energy consumption in CIP section.

Table-- 2:-Steam consumption (kg) in different sections.

S.N.	Section	Day-1	Day-2	Day-3	Average Steam (kg)	Thermal energy(GJ)
1.	**a)Milk pasteurization**	2,215	2,897	2,704	2,605	7.03
	b)cream pasteurization	182	170	216	189	0.51
2.	**CIP**	4,225	4,264	4,128	4,206	11.36
3.	**Butter Making**	107	117	122	115	0.31
4.	**Ghee**	900	1,310	1,195	1,135	3.06
5.	**Dahi and Butter milk**	1,872	1,651	1,690	1,738	4.70
6.	**Crate washing**	1,170	770	488	809	2.18
7.	**Total steam (kg)**	10,671	11,179	10,543	10,797	29.15
8.	**Total thermal energy (GJ)**	28.81	30.18	28.47	29.15	-

(B.1.) Milk and cream pasteurization:
The Average steam requirement in milk pasteurization was found to be 16.7 kg per 1000 kg of milk pasteurization (Table 3). The Average steam requirement in pasteurization of cream in the plant was reported as 26.6 kg per tone of cream processed (Table 4). In both the cases, steam used indicated less amount than reported value by [13] viz. 33.1 kg and 63.6 kg per 1000 kg of sample processed respectively. Average Regeneration efficiency of milk pasteurizer was found as 89%.The Milk Pasteurizer capacity was 20,000 litres/ hour. It consist cream separator and milk homogenizer. The Cream pasteurizer capacity is 3000 litre per hour.

Table-- 3:- Different types of market milk pasteurization and requirement of steam.

S.N.	Type of milk	Day-1	Day-2	Day-3	Average
1.	**Tazza (kg)**	36,400	36,400	37,550	36,783
2.	**Gold (kg)**	21,755	24,130	22,680	22,855
3.	**Chai mazza (kg)**	9,600	11,700	10,100	10,467
4.	**SNT (kg)**	4,845	4,780	4,710	4,778
5.	**TSP (kg)**	15,916	16,700	16,450	16,355
6.	**Loose pasteurized milk(kg)**	56,500	70,310	69,700	65,503
Total milk pasteurization (kg)		1,40,016	1,64,520	1,61,190	155,242

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 8, ISSN No. 2455-2143, Pages 160-165
Published Online December 2022 in IJEAST (http://www.ijeast.com)

Steam consumption (kg)	2,215	2,897	2,704	2,605
Specific steam consumption (kg steam/1000 kg)	15.8	17.6	16.8	16.7
Specific thermal energy consumption(MJ/1000 kg milk)	42.7	47.5	45.4	45.1

Table 4--: Steam consumption in cream Pasteurizer

Parameters	**Day-1**	**Day-2**	**Day-3**	**Average**
Cream (l)	6,812	6,425	8,121	7,119
Steam consumption (in kg)	182	170	216	189
Specific steam consumption (kg steam/1000 kg cream)	26.7	26.5	26.6	26.6
Specific thermal energy consumption(MJ/1000 kg cream)	72.1	71.6	71.8	71.8

.

(B.2.) Butter making:

The Average steam requirement in white butter the plant was reported as 47.22 kg per 1000 kg of butter making (Table 5). The average thermal energy requirement per tone butter making was found to be 127.94 MJ/ tone butter making.

Table--5:- Steam consumption in Butter making is only to preparation of ghee as end product.

Parameters	**Day-1**	**Day-2**	**Day-3**	**Average**
Butter (kg)	2,050	2,750	2,600	740
Steam consumption (in kg)	107	117	122	115
Specific steam consumption (kg steam/1000 kg butter)	52.19	42.55	46.92	47.22
Specific thermal energy consumption(MJ/1000 kg butter)	140.91	114.88	126.84	127.94

(B.3.) Ghee Making:

The thermal energy consumption and steam consumptions in in two different stages butter melting and ghee boiling during the ghee manufacturing. The average steam requirement in ghee making plant was reported as 540 kg per 1000 kg of ghee making. Thermal energy requirement per kg ghee making was found 1458 MJ/1000 kg ghee (Table 6). Thermal energy consumption per 100 kg of ghee preparation was 209792.30 kJ [14].

Table-- 6:- Steam requirement in Ghee making process.

Parameters	**Day-1**	**Day-2**	**Day-3**	**Average**
Ghee (kg)	1,764	2,308	2,172	2,081
Steam consumption (in kg)	900	1,310	1,195	1,135
Specific steam consumption per kg of ghee making	0.51	0.57	0.55	0.54
Specific thermal energy consumption(MJ/kg ghee)	1.377	1.539	1.485	1.458

(B.4.) Dahi and butter milk section:-

The Average steam requirement in dahi making plant was reported as 72.50 kg per 1000 kg of dahi making. The Average steam requirement in butter milk thermization was reported as 59.90 kg per 1000 kg thermization of butter milk (Table 7). Steam used in dahi processing indicated less amount than reported value by [15] 520.35 kg per 1000 kg of processed.

Table --7:- Steam consumption in Dahi and butter milkprocessing section:-

Parameters	**Day-1**	**Day-2**	**Day-3**	**Average**
Dahi production (kg)	4,300	2,800	3,700	3,600
Steam consumption (in kg)	302	201	280	261
Specific steam consumption per 1000 kg of dahi making	70.2	71.8	75.7	72.5
Specific thermal energy consumption(MJ/1000 kg dahi)	189.5	193.9	204.4	195.8
Butter milk (kg) Only thermization	26,500	24,310	23,200	24,670
Steam consumption (in kg)	1,570	1,450	1,410	1,477
Specific steam consumption (kg steam per 1000 kg butter milk)	59.2	59.7	60.8	59.9
Specific thermal energy consumption(MJ/1000 kg butter milk)	159.8	161.2	164.2	161.7

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 8, ISSN No. 2455-2143, Pages 160-165
Published Online December 2022 in IJEAST (http://www.ijeast.com)

(B.5.) Steam consumption of crate washing and CIP sections:
The Average steam consumption was found as 84.3 kg steam per 1000 crate washing (Table 8).Crate washing energy consumption reported by 0.196 kg steam/ crate [18]. The mean requirement of steam per day was reports as 4,206 kg steam/ day in CIP in Plant. Cleaning in place causes a large part of the operating costs, especially in evaporators and dryers where it can account for up to 70% [16] and 10–26% of the energy use for processing. One of the consequences of the high-energy requirements of cleaning in place is that smaller volumes of production consume more energy per unit of output, since the equipment has to be cleaned and started up regularly regardless of the volume [17].

Table-- 8: **Steam consumption of crate washing and Clean-in-place (CIP) section**

Parameters	**Day-1**	**Day-2**	**Day-3**	**Average**
Crate washing	12,040	9,550	6,500	9,363
Steam consumption (in kg)	1170	770	488	809
Specific steam consumption (kg of steam /1000 crate)	97.2	80.6	75.1	84.3
Thermal energy consumption(MJ/1000 crate)	262.4	217.6	202.8	227.6
Steam consumption (in kg) for CIP of plant	4,225	4,264	4,128	4,206
Thermal energy consumption(GJ) in CIP	11.4	11.5	11.1	11.3

(C)Refrigeration:
(C.1.) Refrigeration load: Refrigeration is an essential utility required in a dairy plant for the preservation of milk and milk products and minimizing nutritional losses. The refrigeration system consumes most of the electricity almost 40 to 45 % of total power requirement and hence, has direct impact over the operational cost and therefore, needs proper management. The refrigeration load for different section of dairy plant has been presented in the Table 9. Cold storage is the heart of the dairy industry. The daily refrigeration load in the plant is highest for the cold storage. Average refrigeration consumption in cold storage was found 26,533 MJ for 24 hour operation. Average refrigeration load requirement of dairy plant was found 172.9 TR (Ton of refrigeration).The Plant consist two VCRS have 180 TR capacity.

Table- 9:- Refrigeration load calculation:

Sections	**Refrigeration load (MJ/day)**			
	Day-1	**Day-2**	**Day-3**	**Average**
Raw milk chilling	2,262	2,340	2,309	2,304
Milk pasteurization	5,734	6,737	6,601	6,357
Cream pasteurization	294	277	350	307
Cold storage	23,100	28,500	28,000	26,533
Butter milk pasteurization	263	350	292	302
Total Refrigeration load ,MJ	31,653	37,754	37,552	35,653
Total Load (MJ) after addition 10%	34,818	41,529	41,307	39,218
Refrigeration capacity (TR), if refrigeration plant run 18 h.	153.5	183.1	182.1	172.9

Number of ton of refrigeration (TR) =39218 *1000/(18 x 12600) =172.9

(C.2.) Refrigeration cost of refrigeration plant:
The running cost of refrigeration unit of dairy plant has been presented in the Table 10. Average daily electricity consumption (kWh) was found 5,603. Average operating cost of refrigeration unit (Rs./TR per hour) was found 14.25.

Table--10:- Running cost of refrigeration unit (Rs.) per TR

Parameters	**Day-1**	**Day-2**	**Day-3**	**Average**
Consumption of electricity (kWh)	5,334	5,967	5,508	5,603
running hour	20	22	23	22
Electricity charge (Rs.7.5/ kWh)	40,005	44,753	41,310	42,023
Maintainace charge (2%) of electricity charge	800	897	826	841
Manpower charge (Rs)	1,500	1,500	1,500	1,500

Total running cost (Rs)	42,305	47,150	43,636	44,364
Refrigeration capacity (TR), if refrigeration plant run 18 h.	153.5	183.1	182.1	172.9
Operating cost of refrigeration (Rs./TR per hour)	15.35	14.30	13.31	14.25

IV. CONCLUSIONS

The objective of this study is to provide resources and methods and energy related costs in dairy processing facilities. Using this study, dairy processing facility managers will learn how to manage energy in their facility and uncover opportunities to significantly reduce facility energy consumption. In dairy processing plant, steam was utilized in milk pasteurization, cream pasteurization, butter processing, ghee making, dahi making, butter milk thermization were found as 16.7, 26.6, 47.22, 540.0, 72.50 & 59.90 kg per 1000 kg product, respectively and corresponding thermal energy were 45.1, 71.8, 127.9, 1458.0, 195.8 and 161.7 MJ per 1000 kg product processing. The average steam consumption of crate washing was reported as 84.3 kg steam per 1000 crate. The average refrigeration load requirement of dairy plant was found 172.9 TR and Average operating cost of refrigeration unit was found Rs. 14.25 per TR per hour.

V. REFERENCES

[1]. Katre, B. C. and Murari, K. (2007). Product technology: A crucial aspect of effective energy management, Beverage and food World, April edition, 43-45.

[2]. Shine, P., Upton, J., Sefeedpari, P., and Murphy, M. D. (2020) "Energy Consumption on Dairy Farms: AReview of Monitoring, Prediction Modelling, and Analyses," Energies, vol. 13, no. 5, p. 1288.

[3]. Janzekovic, M. Mursec, B., Vindis, P., Cus, F. (2009). Energy saving in milk processing, Journal of Achievements in Materials and Manufacturing Engineering 33 (2): 197-203

[4]. Mahalingaiah, S., Meeker, J.D., Pearson, K.R., Calafat, A.M., Ye, X. and Petrozza, J. (2008). Temporal variability and predictors of urinary bisphenolA concentrations in men and women. Environ. Health Perspect, 116:173–178.

[5]. Pandya, A. I. (1998). Energy Economics of Indigenous dairy products, A compendium of short\ term training course on energy conservation in dairy processing operations, SMC College of dairy science, Gujarat Agricultural University, Anand.

[6]. Upadhyay,J. B. (1998). Efficiency utilization of steam in dairy processing operations,A compendium of short term training course on energy conservation in dairy processing operations, SMC College of dairy science, Gujrat Agricultural University, Anand.

[7]. Arunachalam, P.K. (1982). Energy accounting in Dairy plants. M.Tech Thesis, Agricultural Engineering Department, IIT Kharagpur.

[8]. Kumar, V. M. and Anand, S. K. (2003). Alternative techniques for extended shelf life (ESL) milk. Indian Dairyman. 55(5): 68-73.

[9]. Singh, R. P. (1978). Energy accounting in food process operations. Food Technol., 32(4) : 40–46.

[10]. Knopf, F.C., Wilson, P.W. and Okos, M.R. (1978). Energy utilization in a daily processing plant. ASAE paper No. 78-652/ Dept. of Agricultural Engineering, Purdue University, U.S.A.

[11]. Das, H. (2005). Food Processing Operation Analysis, 1st edition, Asian Books Private Limited, New Delhi, India.

[12]. Hvid J. (1992) Review of energy efficient technologies in the dairy industry sector. Copenhagen: Energy Centre Denmark.

[13]. Gedam, K. H. (1996). Energy consumption in a commercial dairy plant.M. Tech. Thesis, Agricultural Engineering Department, IIT, Kharagpur.

[14]. Abichandani, H. and Sarma, S.C. (1978). Process feasibility of ghee making by direct contact heat exchange. J Food Sci. & Tech. (India), 15(5) : 177-183.

[15]. Prabhakar, P.K., Srivastav, P.P., and Murari, K. (2015). Energy consumption during manufacturing of different dairy products in a commercial dairy plant: a case study. Asian J. Dairy & Food res., 34(2) 2015, 98-103

[16]. De Jong P, Verdumen REM. (2001). Concentrated and dried dairy products. In: Tamime A, Law B, editors. Mechanization and automation in dairy technology. Sheffield: Sheffield Academic Press; p. 95–118.

[17]. Høgaas E. (2002). Life cycle assessment of industrial milk production. The International Journal of Life Cycle Assessment; 17:115–26.

[18]. Kumar N., Prabhakar K.P., MeenaG.S. , Kishore A. and Halder K. (2017).Effective energy management in a commercial multiproduct dairy plant through a graphical user interface. The Pharma Innovation. 6(11): 193-198