RESEARCH ARTICLE

Electrical energy usage for processing of milk and milk products in a dairy plant – a case study

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Abstract: The electrical energy analysis was performed in processing and production of selected dairy products in a commercial dairy plant having installed capacity of 1.0 lakh lit./ day. The purpose of the analysis was to determine the electrical energy usage in the processing line so that better efficacy in energy usage can be achieved. Engineering services in dairy plants are considered to be areas where simple plant optimization measures can lead to substantial and immediate savings. In general, dairy plant is considered to be an energy intensive industry where electrical energy is the major energy source utilized. In this experimental dairy plant, the electricity utilized for liquid milk processing, cream processing, ghee making, Cheddar cheese manufacture, Mozzarella cheese manufacture and paneer preparation was found to be 0.88, 8.93, 2.77, 2.17, 6.45 and 1.45 kWh/100 kg product respectively. For ice cream preparation, the electricity utilized was found to be 4.77 kWh per 100 lit.

Keywords: Energy, electric, dairy, milk, milk products

Introduction

India is the world's largest producer of milk with production figure of over 130 million tonnes during 2012-13 (Anon., 2013). Out of the total milk production in the country, about 45.0 % of milk is used for direct consumption and remaining 55.0 % is processed into different milk and milk products. The dairy industry requires energy in large amount to process milk and also to convert milk into an array of dairy products. The projected per capita energy consumption for India in the year 2011-12 was estimated to be 546 million tonnes of oil equivalent (MTOE) which is just 20.0 % of energy usage in USA and 4.0 % of the world's average energy usage. The total installed capacity of electric power generation in India was 2,84,634 MW in March 2014. Of this, 2,45,259 MW (86.16 %) was accounted by utilities and 39,375 MW (13.84 %) by captive power plants. Amongst the utilities, 68.60 % (i.e. 1,68,258 MW) capacity was accounted by thermal power plant (58.60 per cent coal, 9.01 % gas and 0.52 % diesel); 16.53 % (i.e. 40,531 MW) by hydro; 1.95 % (i.e. 4,780MW) by nuclear, and 12.92 % (i.e. 31,690 MW) by renewable energy source based power plants. About 75.0 % of the coal produced worldwide is being used for electricity generation (CEAI, 2015).

Energy is a critical input for the production and consumption activities in the development of economy of any country. Land, labour, capital and energy are the four factors for production of dairy products. Energy consumption is a measure of prosperity (Panda, 1988). Energy intensity is the energy consumption per unit of gross domestic product (GDP). India's energy intensity is 3.7, 1.55, 1.47 and 1.5 times that of Japan, USA, Asia and world average, respectively (Desai and Zala, 2010).

The major commercial energy consuming sectors in the country are classified into five major sectors namely agriculture, domestic, industry, transport and others. Among these the industry remains the biggest consumer with 49.0 % share in total commercial energy consumption, followed by transport 22.0 %, domestic 10.0 %, agriculture 5.0 % and the remaining 14.0 % (Shahi, 2006).

The industrial sector is the major energy consuming sector in India and uses about 50.0 % of total commercial energy available in the country. The total industrial energy consumption, including non energy uses, grew from 45.7 MTOE in 1984-85 to 74.0 MTOE in 1994-95. Of the commercial sources of energy, coal and lignite accounted for about 56.0 %, oil and natural gas around 40.0 %, hydro electric power about 3.0 % and nuclear power accounted for 1.0 % (Tyagi, 2003). It is an established fact that "Energy saved is energy generated".

Energy inputs in the dairy plants are in two forms i.e. electrical energy and thermal energy (steam). Electrical energy is used as motive power and for lighting, space heating, etc. Electricity is mainly utilized as motive power (@ 75.0 % of total electrical energy) in dairy plant for pumping of fluid, and for operating various equipments such as can/bottle washers, bottle

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filler, clarifier, milk/cream pasteurizers, compressor, evaporator, homogenizer, cream separator, butter churn, etc.

Materials and Methods

The electrical energy is mainly utilized by centrifugal pump for transferring the milk and milk products (fluid condition) from one place to another except for lobe pump that is used for transferring cheese coagulum in cheese making and molten butter in ghee manufacture. The prime mover electric motors are employed for proper operation of the agitator by converting electrical energy into mechanical energy. The milk and milk products manufacturing include milk processing, ice cream manufacturing, butter and ghee manufacture, paneer making; and Cheddar and Mozzarella cheese making. The materials and methodology adopted for accounting of the electrical energy consumption for the above mentioned processing are outlined herein (Anon, 2005).

i) Rated data mentioned on the electrical equipment were noted i.e. the rated power in hp (kW), voltage (v), current (A), efficiency (%) and power factor.

ii) Average running hours of all electrical equipment during the processing were observed.

iii) Current, voltage and power factor of electric equipment were measured using power analyzer (NANOVIP Plus) or digital clamp meter (MECO)

iv) Power consumption was calculated using the formula:
3 phase AC wire equipment: $P=\sqrt{3}\ VI\cos\Phi$
Single phase AC wire equipment: $P= VI\cos\Phi$

Where P, V, I and cosΦ are actual power consumption, voltage, current and power factor respectively.

v) The actual load of motor was calculated using the formula given by Bureau of energy efficiency (Anon, 2005).

$$P_{ir} = \frac{\text{Name plate full rated Kw}}{\eta_{fl}}$$

Where, P_{ir} = Input power at full-rated load (kW)

η_{fl} = Efficiency at full-rated load (%)

$$\text{Load (\%)} = \frac{Pi}{Pir} \times 100$$

Pi = Measured three-phase power in kW

Results and Discussion

The dairy plant selected for the study had milk handling capacity of 1,00,000 Lit. per day. Table 1 shows the details of the equipments used for the milk and milk products processing, their capacities, hours of working per day and motor HP. Table 2 and Table 3 shows the yield of dairy products and operating temperatures for the relevant processes respectively. On this basis, the following results for the electrical energy were obtained for milk and milk product processes.

Milk Processing: Figure 1 shows the electrical energy consumption in unit operation during processing of 1,00,000 Lit. of milk per day. Milk reception required less electrical energy, while milk packaging required high quantum of electrical energy. The electrical energy consumption per 1,00,000 Lit. of milk processed during milk reception, pasteurization, packaging and crate washing was found to be 137.49, 288.78, 308.78 and 142.15 kWh, respectively. In packaging section, the packaging machines of higher capacity consumed lower electrical energy as compared to lower capacity machines. Thus, higher capacity packaging machines are recommended since they can save 30.0 % of the electrical energy.

Butter production: Figure 2 shows the electrical energy consumption in various unit operations involved in cream (45.0% fat) processing in order to obtain white butter (82.0 % fat). Ageing of pasteurized cream for butter making entails lower electrical energy than does churning of cream by Continuous butter making machine. The electrical energy consumption in producing 1,000 kg of butter involves 28.15 kWh for cream pasteurization, 21.36 kWh for cream ageing and 39.78 kWh for churning of cream.

Ghee manufacture: Figure 3 shows the electrical energy consumption in various unit operations in ghee manufactured by 'Creamery butter' method, employing 'pre-stratification' technique (Ray and Chatterjee, 1955). Butter melting required major portion of the electrical energy, while heat clarification (111°C) in ghee making necessitated lower electrical energy. The electrical energy consumption for producing 1000 kg of ghee involved usage of 11.33 kWh for butter melting, 2.3 kWh for heat clarification, 5.36 kWh for ghee filtration and 8.76 kWh for ghee packaging and storage.

Ice cream preparation: Figure 4 shows the electrical energy consumption in different unit operations for producing 500 kg of ice cream mix and its subsequent pasteurization. Mix pasteurization comprised of major electrical energy, while agitation in storage tank in ice cream mix preparation required lower electrical energy. The electrical energy consumption in producing 500 kg of ice cream mix involved 0.75 kWh for blending, 1.43 kWh for preheat treatment, 0.86 kWh for agitation and 5.22 kWh for pasteurization of ice cream mix. The total electricity consumption was 8.53 kWh for producing 500 kg of ice cream mix.

Figure 5 shows the electrical energy consumption in different unit operations in producing 1,000 Lit. of ice cream (100 % overrun) which includes ice cream mix cooling and ageing, and

Table 1: Particulars of the equipment used for processing of milk and milk products

Process type	Equipments	Capacity	Operating time (in 24 h)	Motor (hp)
Milk pasteurization	Milk transfer pump and Hot Water Pump (Centrifugal type)	10,000 LPH	12 :00	11
Cream separation	Cream separator (Alfa Laval)	10,000 LPH	6 :00	15
Homogenization	Milk homogenizer	10,000 LPH	2:00	75
Cream pasteurization	Cream transfer pump and Hot Water Pump (Centrifugal type)	2,000 LPH	6:00	7.5
Milk storage	Milk silo (tanks) with agitator (5 Nos; 30,000 liters and 1 Nos; 25000 liters)	1,75,000 Lit.	12:00	17
Milk packaging	Double head Form-Fill-Seal (FFS) packaging machine	6500 LPH	12:00	28
Crate washing	Centrifugal pump for primary rinse, detergent & final rinse, and gear box motor for conveyor	720 Crates/h	12:00	16
Cream ageing	Ageing tank , chilled water supply pump and cream transfer pump (Lobe pump)	5000 Lit..	6:00	8
Cream churning	Continuous Butter Making Machine (HMT Ltd. Aurangabad)	800 kg/h	4:00	14
Ghee manufacture	Butter melting tank, transfer pump, pre-stratification tank, centrifugal clarifier and storage tank.	1000 LPH	2:30	8.5
Ghee making	Ghee kettle heated using steam	1500 Lit.	2:30	1.5
Ghee packaging	Single head FFS machine	600 LPH	2:00	3
Ice cream mix preparation	Blender, centrifugal pump for recirculation and hot water, and mix storage tank	2000 LPH	1:30	13
Ice cream mix processing	centrifugal pump for feeding of mix and hot water in pasteurizer	2000 LPH	1:30	11
Ice cream Mix Homogenization	Homogenizer	2000 LPH	1:30	10
Ice cream mix ageing tank	Bulk cooler and centrifugal pump	4000 liters	4:00	15
Ice cream mix freezing	Continuous ice cream freezer (3 Nos., Tetra Pak, IDMCand Synergy Make)	800 LPH	6:00	27
Fruit feeding	Fruit feeder (Panchal Workshop, Vitthal Udyognagar)	6 kg/h	6:00	1.2
I/C cup filling	Rotary cup/cone filling machine	4000 cup /h	6:00	0.5
Ice cream hardening	Fan motor in hardening room	10,000 Lit.	12:00	3.0
Cheese vat	Cheese vat agitator motor, lobe pump, acid dosing pump	6000 Lit.	2:00	4
Cheese working table	Whey transfer pump	1500 Lit	1:00	7
Cheese stretching	Stretching machine (CE Dima) and centrifugal pump for chilled and hot water	250 kg /h	2:00	8
Cheese/paneer packaging	Single head vacuum packing machine (Multivac)	600 kg /h	4:00	6

Table 2: Particulars of raw material and per cent yield of specific dairy products

Product	Composition of raw material (standardized milk/cream/butter)	Yield (%)
Paneer	Milk :.6.0% fat, 8.6% SNF	14.59
Cheddar cheese	Milk :3.5% fat, 2.65% casein	11.55
Mozzarella cheese	Milk: 2.5 % fat, 2.65% casein	10.07
Butter	Pasteurized cream : 45.0% fat, 0.08% LA	55.00
Ghee	White butter: 82.0 % fat	80.00

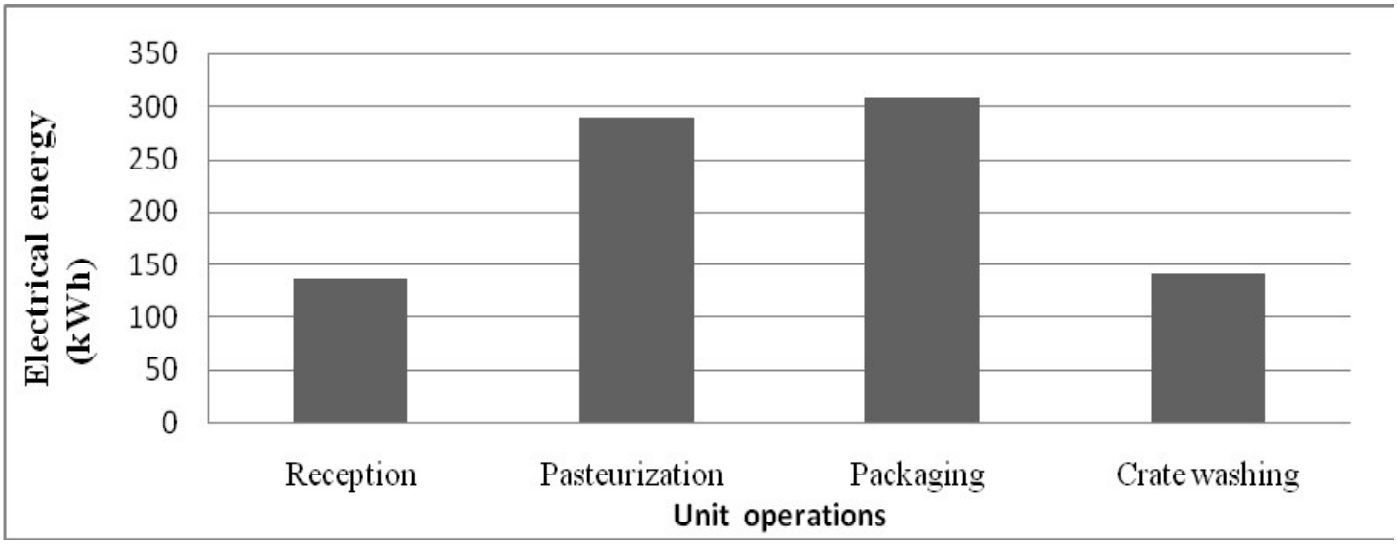

Fig. 1: Electrical energy consumption during milk processing (100000 lit/day)

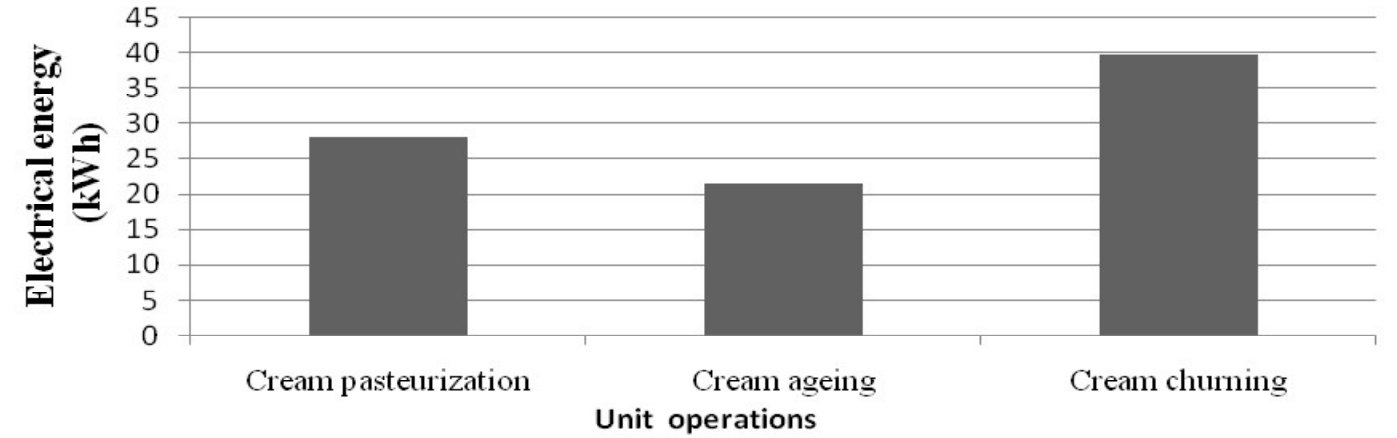

Fig. 2: Electrical energy required for producing 1000 kg butter

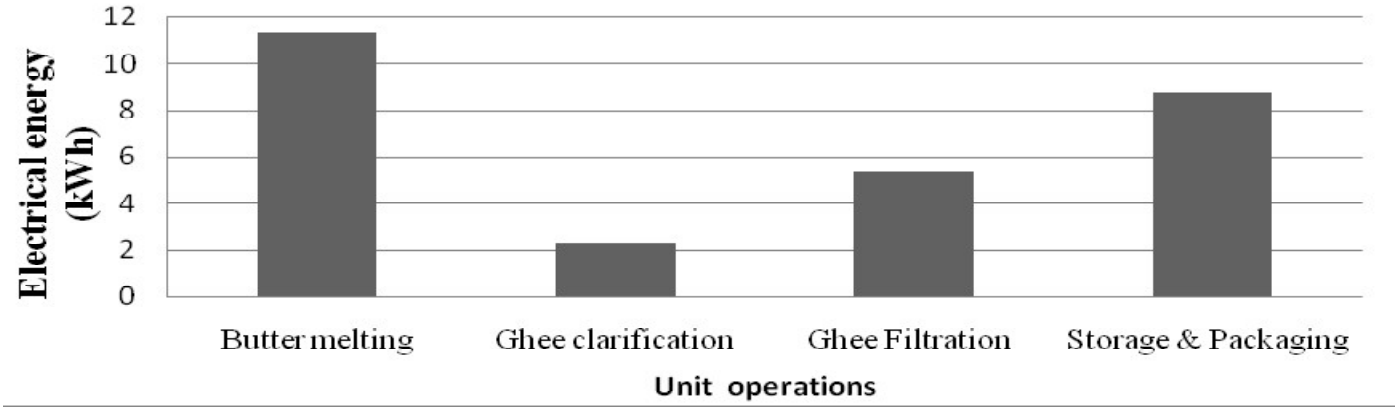

Fig. 3: Electrical energy required for producing1000 kg ghee

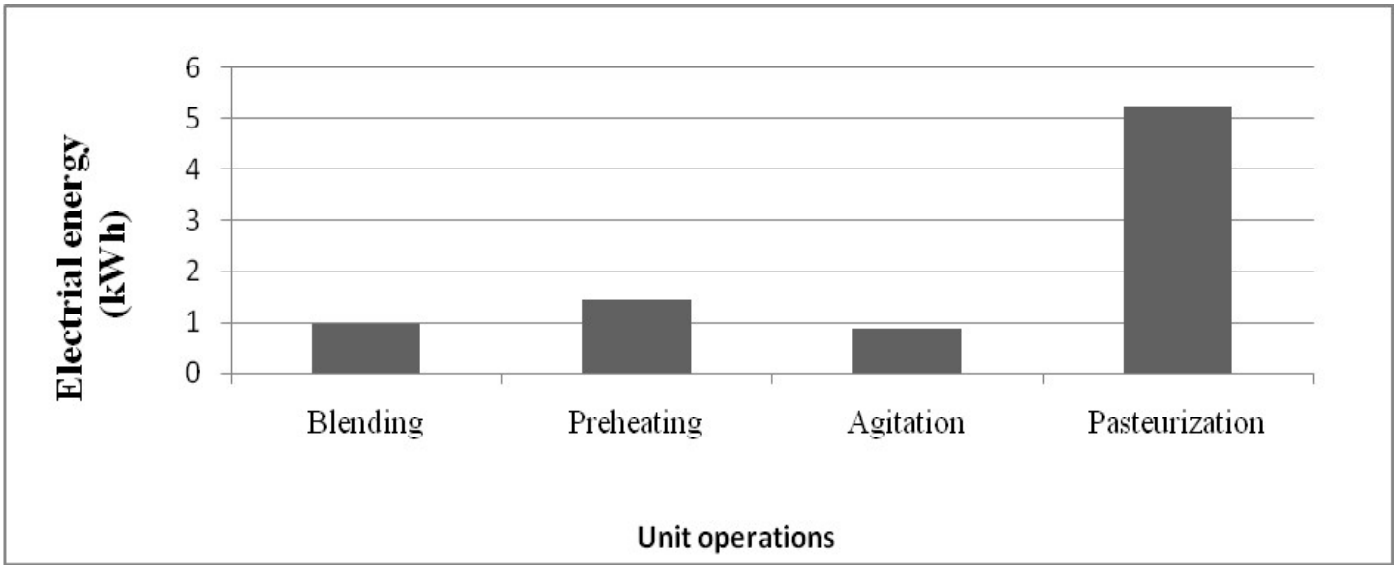

Fig. 4: Electrical energy consumed in preparing 500 kg ice cream mix

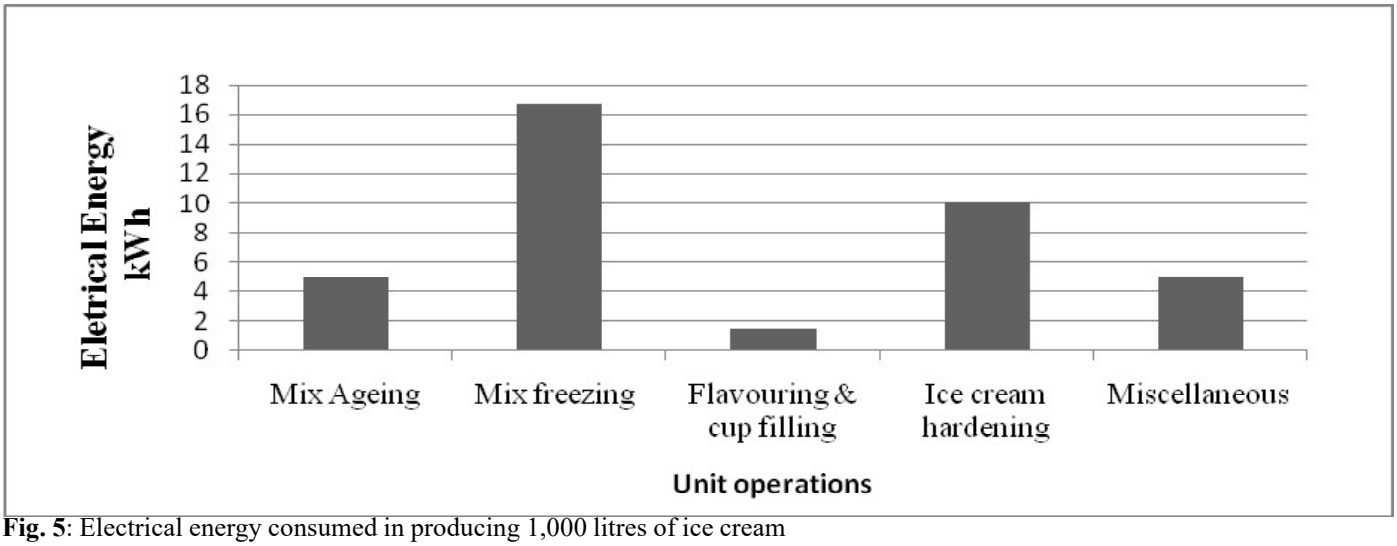

Fig. 5: Electrical energy consumed in producing 1,000 litres of ice cream

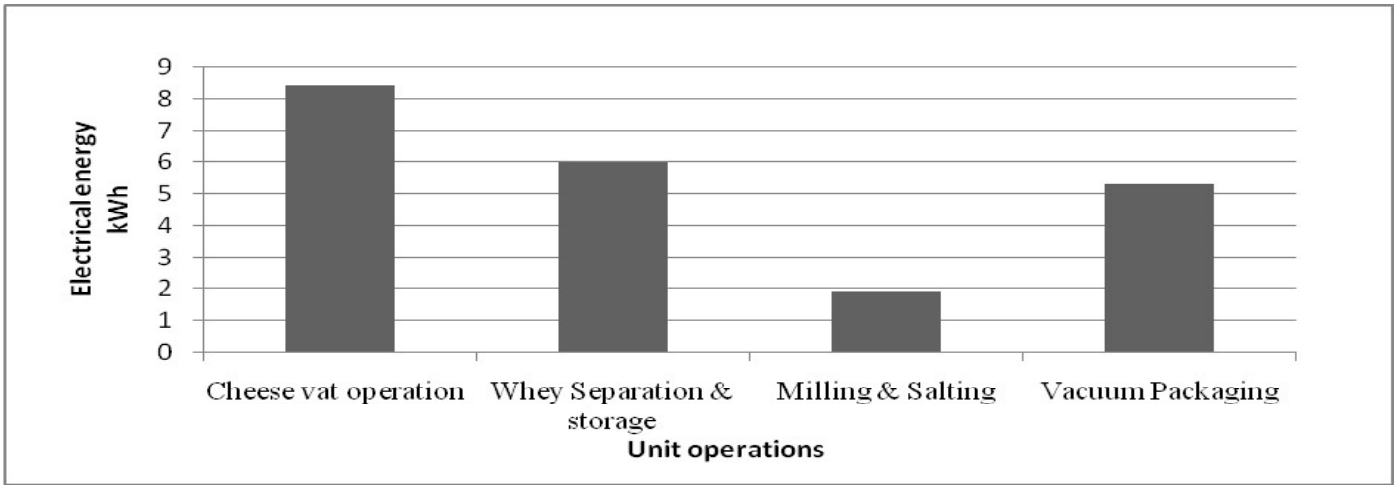

Fig. 6: Electrical energy consumed in producing 1,000 kg Cheddar cheese

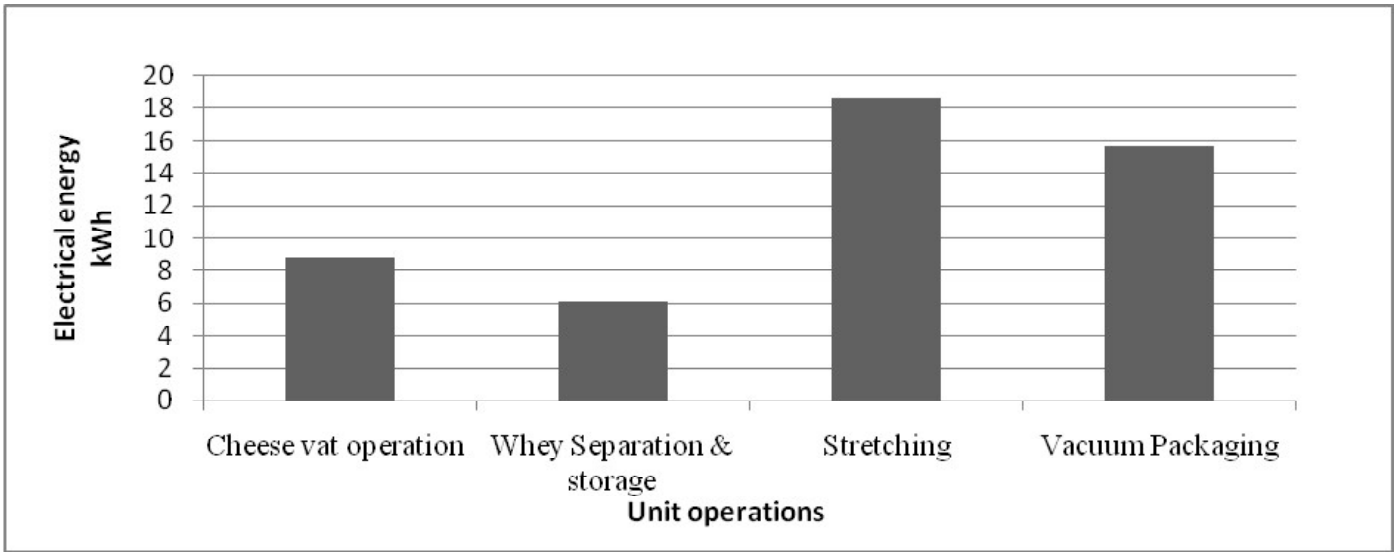

Fig. 7: Electrical energy consumed in producing 1,000 kg Mozzarella cheese.

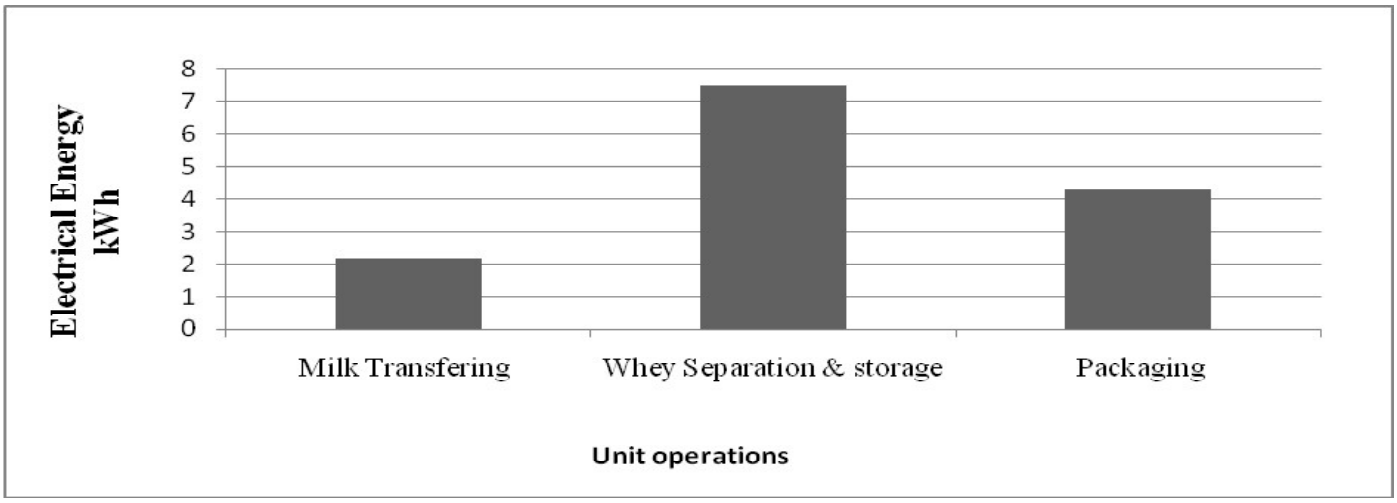

Fig. 8: Electrical energy consumed in producing1000 kg *paneer*

Fig. 9: Schematic diagram representing specific electrical energy consumption (kWh) in producing 100 kg of dairy products
*The above data excludes electrical energy consumption for milk pasteurization.

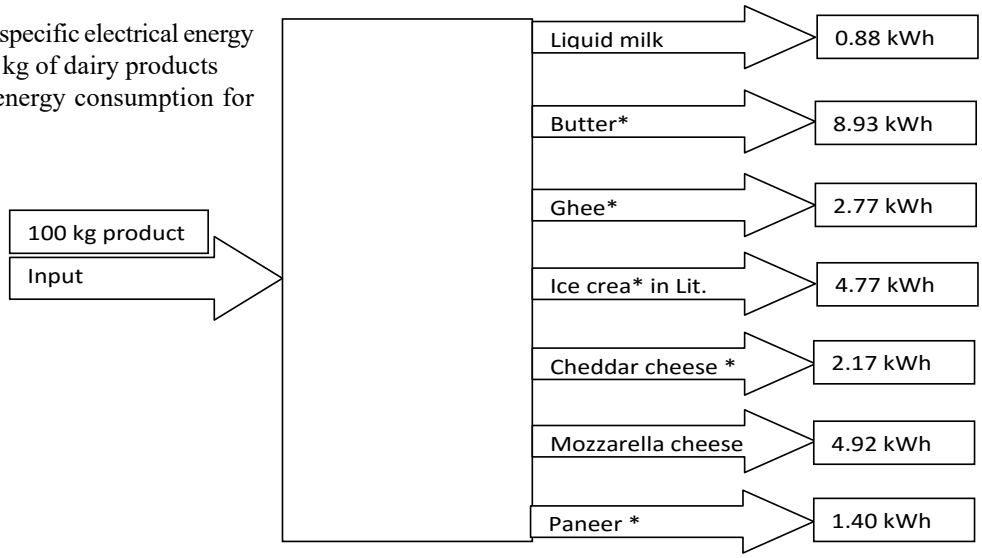

Table 3: Process details involved in milk processing or in preparing specific dairy products

Process type	Temperature (^{O}C)
Milk pasteurization(a)Heating temperature (b)Chilling temperature	(a) 78.0 (b) 3.5
Homogenization temperature	70.0
Milk preheating prior to coagulation in paneer making	82.0
Final clarification temperature in ghee making	111.0
Cheddar cheeseCooking temperature (Initial to final)	31.2 to 37.2
Mozzarella cheese	
(a)Cooking temperature (Initial to final)	31.5 to 37.5
(b)Moulding water temperature for stretching cheese curd	78.0

it's freezing into ice cream. The freezing process was energy intensive, while flavouring and cup filling (100 ml cup size; 4000 cups/h capacity) consumed lower electrical energy. The electrical energy consumption in ice cream mix ageing, pumping, freezing, flavouring and cup filling; ice cream hardening and miscellaneous operations were found to be 4.89, 1.12, 16.68, 1.54, 10.00 and 5.02 kWh, respectively when producing 1,000 Lit. of ice cream. The total electricity consumption for producing 1,000 Lit. of ice cream was 39.25 kWh.

Cheddar cheese preparation: Figure 6 shows the electrical energy consumption in different unit operations involved in producing 1,000 kg of Cheddar cheese. The operations relating to cheese vat consumed the major share of electrical energy, while milling and salt mixing consumed lower electrical energy. The electrical energy consumption in cheese vat operations, whey separation and storage, milling and salting, and vacuum packaging were found to be 8.40, 6.00, 1.94 and 5.33 kWh, respectively when producing 1000 kg batch of Cheddar cheese. The total electricity consumption in producing 1000 kg Cheddar cheese was 21.67 kWh.

Mozzarella cheese preparation: Figure 7 shows the electrical energy consumption in different unit operations involved in production of 1,000 kg of Mozzarella cheese. Stretching operation assumed the major share of the electrical energy usage, while whey separation and storage consumed lower electrical energy. The electrical energy consumption during cheese vat operation, whey separation and storage, stretching, and vacuum packaging were arrived at 8.80, 6.10, 18.63 and 15.70 kWh respectively in producing 1000 kg of Mozzarella cheese. The total electrical energy usage in producing 1,000 kg Mozzarella cheese was 49.23 kWh. For Mozzarella cheese, vacuum packaging consumed three times more electrical energy as compared to Cheddar cheese because Mozzarella cheese was sliced into different pack size i.e. 200 g and 1000 g; such slicing operation was not carried out for Cheddar cheese.

Paneer preparation: Figure 8 shows the electrical energy consumption in different unit operations involved in producing 1000 kg of *paneer.* Whey separation and storage consumed the major electrical energy usage, while packaging of *paneer* required the least electrical energy. The electrical energy consumption required in milk transferring, whey separation and storage, and packaging were 2.18, 7.5 and 4.3 kWh, respectively for producing 1000 kg *paneer.* The total electricity consumption for producing 1000 kg *paneer* was 14.0 kWh.

Specific electrical energy consumption (SEEC): The specific electrical energy consumed per 100 kg of product processing is shown in Figure 9. The electrical energy usage (for 100 kg product, except for ice cream which was expressed per 100 lit.) for liquid milk processing -0.877 kWh, for butter production - 8.93 kWh, for ghee production - 2.77 kWh, for Ice cream production – 4.77 kWh, for Cheddar cheese production - 2.17 kWh, for Mozzarella cheese production – 4.92 kWh and for *paneer* production - 1.4 kWh.

Conclusions

The total electrical energy required in processing of seven products (including milk processing) was computed to be 25.84 kWh and specific electrical energy consumption was arrived at 3.69 kWh per 100 kg. Among these products, manufacture of butter, ice cream and Mozzarella cheese was the major contributor to energy usage; the actual energy usage compared to the total electrical energy requirement was worked out to be 34.55, 18.46 and 19.04 % respectively for butter, ice cream and Mozzarella cheese making. The overall electrical energy loss observed was to the tune of 7.89 % of the total electrical energy input.

The electrical energy efficiency of the dairy plant (for this capacity) was found to be 'satisfactory' based on the various process requirements and energy management, with minimum loss of energy. However, there exists scope in improving the energy efficiency of dairy plant either by use of high energy efficient motors or improved power factor by adding respective capacitors.

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