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Performance Evaluation of On-farm Raw Milk Cooling System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This experiment was conducted with an aim to evaluate novel on-farm raw milk cooling system (OFMC). The system consisted of plate cooler, cooling cum storage tank and thermal storage tank. Conventional bulk milk cooling system was considered as control (CMC). The raw milk cooling systems were evaluated for overall heat transfer co-efficient, rate of cooling, coefficient of performance, total energy consumption and total cost of raw milk cooling. Raw milk cooling in OFMC was completed within 30 min whereas CMC took more than 2h to cool raw milk to 4°C. For OFMC, the U value of plate cooler when milk cooled to 4°C was 872.03 W/m^2 °C. The average overall heat transfer coefficient of cooling cum storage tank for milk cooling in the evening and morning were 359.0 W/(m^2 °C) and 350.2 W/(m^2 °C) respectively. The average U value for thermal

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storage was 121.65 W/m²°C. The COP of the OFMC ranged from 3.97 to 2.36 during day time ice formation and 4.34 to 2.47 during night time ice formation. The average COP of the system was higher during night time compared to day time. When cost of electricity considered at ₹ 9.7 per kWh, cooling cost per litre of milk for OFMC and CMC were ₹ 0.2939 and ₹ 0.3589, respectively. The energy consumed in CMC was higher than the OFMC. Such on-farm raw milk cooling system can be a better option than conventional bulk milk coolers.

Keywords: Raw milk; plate cooler; milk cooling system; energy; cooling cost.

1. INTRODUCTION

Milk is a classic superior food that contains vital nutrients for the bodies of young mammals [1]. The fresh milk drawn from the healthy dairy animal is found to be devoid of microorganisms. It leaves the udder at a temperature of around 37°C, which favours bacterial growth [2]. Milk is an excellent growth medium for bacteria [3].

Kakati et al. [4] assessed the quality of raw milk sold in and around Guwahati city based on the microbial load. All of the raw milk samples had a significantly higher standard plate count and coliform count than the permissible standard. It was concluded that raw milk sold in most parts of Guwahati city do not confer to the legal microbiological standard and may pose a high risk of milk-borne illness among consumers of the city. Counts were slightly higher in milk collected during the summer months while cows were grazing outside [5,6]. Many psychrotrophic bacteria are capable of producing heat stable enzymes like proteases and lipases and cause degradation and reduction in the shelf-life of pasteurized milk and milk products [3,7]. Hence, cooling of raw milk at milking shed or at milk collection centres has become the first line of action to arrest bacterial growth and sustain the quality of milk produced. Decreased temperature slows bacterial growth dramatically, and thus it is quite important to make sure that raw milk is rapidly chilled to 38°F (3.3°C) within an hour of milking to slow bacterial growth [8].

Entrepreneurs in India are now attempting to reach out directly to their customers using farm fresh milk. The consumer has begun to recognise the importance of fresh, pure milk, and this niche of high-paying customers is likely to rapidly grow to smaller communities [9]. Doni and Chauhan [10] reported economic efficiency of milk procurement in Sirsa Cooperative Milk Plant, Haryana. The average chilling cost per litre of milk was found to be 0.36 per litre for a place. The study showed that among all the cost constituent in procurement process transportation cost had the highest share (43.72 per cent) followed by collection cost (26 per cent), chilling cost (21.86 per cent) and reception cost (8.20 per cent). Today's dairy farms face difficulties due to fast growing energy prices and environmental concerns. Determining the best energy efficiency and energy management opportunities for dairy farms help reduce energy costs, enhance environmental quality and increase productivity and profitability. Energy efficiency is frequently a low-cost, quick and easy approach to save money.

This study was conducted at the cow farm of Anand, Gujarat (India) with the aim to study the performance of on-farm raw milk cooling system and to calculate the total energy consumption. The goal of this research was to see how rapid cooling of raw milk affected energy consumption and saving in electricity at farm level in comparison to conventional milk cooling system. On-farm raw milk cooling system was developed for rapid cooling of raw milk at dairy farm. Rapid cooling of milk reduces the temperature of milk in very short time and hence controls growth of microbes. For this, milk cooling system includes cooling cum storage tank connected with plate cooler such that first stage of milk cooling takes place in plate cooler followed by second stage of cooling in cooling cum storage tank.

2. MATERIALS AND METHODS

The on-farm raw milk cooling which is mentioned in our earlier published research study [11] was evaluated for its performance in the current experiment. The conventional milk cooling system i.e., bulk milk cooler, was used as a control.

2.1 On-farm Raw Milk Cooling System (OFMC)

In OFMC, piping connections for milk flow was provided from balance tank, milk supply pump, plate cooler and cooling cum storage tank. Plate cooler and cooling cum storage tank were provided with chilled water supply and return lines connected to inlet and outlet of thermal storage system. Piping connections for thermal storage was provided such that chilled water circulates either through plate cooler or cooling cum storage tank. Milk supply pump, chilled water supply pump and condensing unit of vapour compression refrigeration system (VCRS) were connected with three phase power supply. Control panel and temperature display screen were mounted on wall. The system was installed on the roof with good ventilation for proper functioning of the condensing unit. Milk outlet at the bottom of cooling cum storage tank was provided for tanker dispatch of raw milk in the morning. Photograph of OFMC is shown in Fig. 1.

2.2 Control Raw Milk Cooling System (CMC)

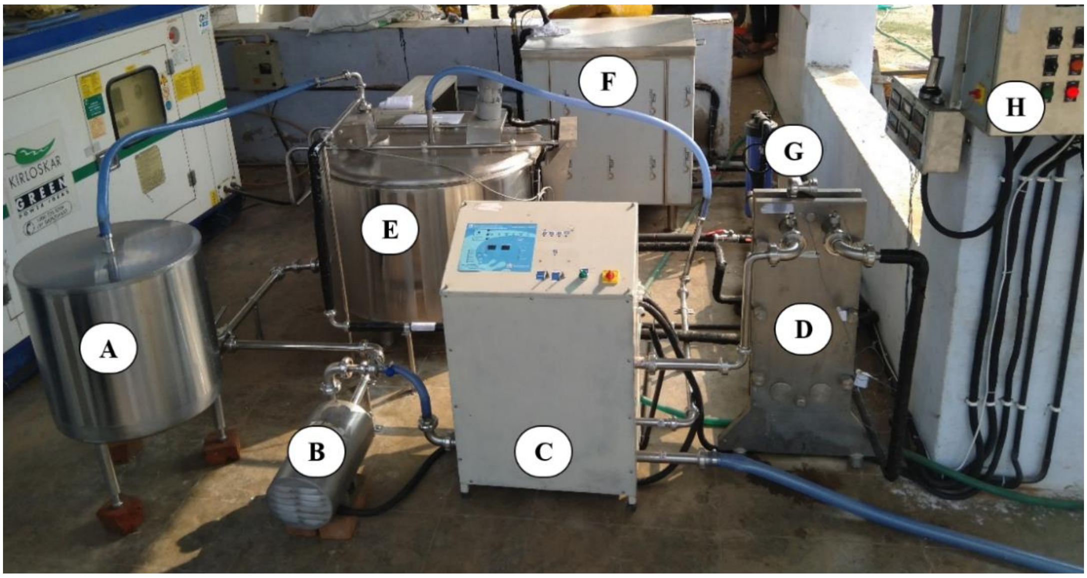
In control cooling system, milk was transferred from milking machine to buffer tank through piped connection. Milk from buffer tank to bulk milk cooler was transferred through milk transfer pump-1. Whereas milk collected in balance tank from manual milking was transferred to bulk milk cooler through milk supply pump-2. Condensing unit for R-22 was connected with bulk milk cooler. Milk outlet at the bottom of bulk milk cooler was provided for tanker dispatch of raw milk in the morning. Photograph of CMC is shown in Fig. 2.

2.3 Milking and Cooling Procedure

Cows were milked twice a day i.e., during evening and morning and therefore collection and cooling of raw milk was done twice a day. Raw milk collected through machine milking was transferred into OFMC and CMC simultaneously for cooling to 4°C.

In case of CMC for the evening milk cooling, raw milk was cooled to 4°C using direct expansion refrigeration system attached to it whereas in OFMC, raw milk was cooled to 4°C through plate cooler using chilled water and then it was transferred to cooling cum storage tank where its temperature was maintained at 4°C using chilled water during storage. These milks were stored overnight at 4°C in respective milk cooling system. In the morning, same procedure was followed for raw milk cooling. Hence, raw milk at 34°C received from morning milking was added to previous day evening's raw milk maintained at 4°C.

Both the systems were operated at 50% storage capacity in the evening and remaining 50% in the morning such that system is capable to cool milk as per the ISO-5708. For the OFMC, the required quantity of ice was formed in thermal storage system well before each milk cooling cycle.



A	*:*	*Balance tank*	*E*	*:*	*Cooling cum storage tank*
B	*:*	*Milk supply pump*	*F*	*:*	*Thermal storage system*
C	*:*	*Auto CIP*	*G*	*:*	*Chilled water supply pump*
D	*:*	*Plate cooler*	*H*	*:*	*Main control panel*

Fig. 1. On-farm milk cooling system

A	*:*	*Bulk milk cooler (BMC)*	*D*	*:*	*Temperature display for BMC*
B	*:*	*Buffer tank for machine milking*	*E*	*:*	*Milk transfer pump from buffer tank to BMC*
C	*:*	*Balance tank for manual milking*	*F*	*:*	*Milk transfer pump from balance tank to BMC*

Fig. 2. Control milk cooling system

2.4 Heat Transfer Analysis of OFMC

In the OFMC, heat transfer took place between raw milk and chilled water in plate cooler, between refrigerant, water and ice in thermal storage. Heat transfer coefficient of plate cooler, cooling cum storage tank and thermal storage were evaluated for morning and evening milk cooling. This analysis was useful to compare the heat transfer rate among plate cooler, cooling cum storage tank and thermal storage. Temperature of milk and chilled water entering and leaving the plate cooler was measured by temperature sensor (PT-100). COP of refrigeration system of thermal storage was evaluated for evening and morning milk cooling.

The heat transfer analysis of OFMC was carried out at optimized precooling temperatures. Calculation of overall heat transfer coefficient for plate cooler is given below.

$$U = \frac{Q}{(A \times LMTD)}$$

Where,

U	=	Overall heat transfer coefficient (W/m^2 °C)
Q	=	Heat removed from milk (J/s)
	=	$m \times Cp \times \Delta T$
m	=	Mass flowrate of milk (kg/s)
	=	$V \times \rho$
V	=	Volume flowrate of milk (m^3/s)
ρ	=	Density of milk (kg/m^3)
Cp	=	Specific heat of milk (J/kg °C)
ΔT	=	Temperature drop of milk per unit time (°C)
A	=	Area of heat transfer (m^2)
	=	Area per plate × No. of plates
LMTD	=	Logarithmic Mean Temperature Difference (°C)
	=	$(\Delta T_1 - \Delta T_2) / \ln (\Delta T_1/\Delta T_2)$
ΔT_1	=	$T_{mi} - T_{co}$ (°C)
ΔT_2	=	$T_{mo} - T_{ci}$ (°C)
T_{mi}	=	Temperature of milk at the inlet of plate cooler (°C)
T_{mo}	=	Temperature of milk at the outlet of plate cooler (°C)
T_{ci}	=	Temperature of chilled water at the inlet of plate cooler (°C)
T_{co}	=	Temperature of chilled water at the outlet of plate cooler (°C)

Calculation of overall heat transfer coefficient for cooling cum storage tank is given below.

U	=	$\frac{Q}{(A \times LMTD)}$
Where,		
U	=	Overall heat transfer coefficient (W/m^2 °C)
Q	=	Heat removed from milk (J/s)
	=	$m \times Cp \times \Delta T$
m	=	Mass of milk (kg)
m	=	V × ρ
V	=	Volume of milk (L)
ρ	=	Density of milk (kg/L)
Cp	=	Specific heat of milk (J/kg °C)
ΔT	=	Temperature drop of milk per unit time (°C)
A	=	Heat transfer area of pillow plate (m^2)
LMTD	=	Logarithmic Mean Temperature Difference (°C)
	=	$(\Delta T_1 - \Delta T_2) / \ln(\Delta T_1/\Delta T_2)$
ΔT_1	=	$T_{mi} - T_{co}$ (°C)
ΔT_2	=	$T_{mo} - T_{ci}$ (°C)
T_{mi}	=	Initial temperature of milk in cooing cum storage tank (°C)
T_{mo}	=	Final temperature of milk in cooing cum storage tank (°C)
T_{ci}	=	Temperature of chilled water at the inlet of cooing cum storage tank (°C)
T_{co}	=	Temperature of chilled water at the outlet of cooing cum storage tank (°C)

2.5 Performance Evaluation of Thermal Storage System

Performance of thermal storage system was evaluated by calculating overall heat transfer coefficient and COP. Calculation of overall heat transfer coefficient for thermal storage system is given.

Evaporating and condensing pressure of R-22 refrigerant were recorded from pressure gauge installed at suction and discharge of the compressor. The COP of the thermal storage system was analyzed from evaporating and condensing pressure of R-22 using compressor manufacturer software tool SELECT 8 for day and night time ice formation.

Sensible heat & latent heat removal		
U	=	$\frac{Q}{(A \times LMTD)}$
Q	=	$Q_{sensible} + Q_{latent}$ (J/s)
Only latent heat removal		
U	=	$\frac{Q\ latent}{(A \times LMTD)}$
$Q_{sensible}$	=	Sensible heat removed from water (J/s)
	=	$Mw \times Cp \times dt$
M_w	=	Mass of water (kg)
Cp	=	Specific heat of water (J/kg °C)
dt	=	Temperature drop of water per hour (°C)
M_i	=	Mass of ice formed per hour (kg)
Total volume of ice with tube	=	$[\frac{\pi}{4} \times (\text{Diameter of ice with tube})^2 \times \text{ tube length}]$ (m^3)
Volume of tube	=	$[\frac{\pi}{4} \times (\text{Diameter of tube})^2 \times \text{ tube length}]$ (m^3)
Total volume of ice without tube	=	(Volume of ice with tube - Volume of tube) (m^3)
Total mass of ice	=	(Total volume of ice without tube × density of ice) (kg)
Mass of ice per hour (M_i)	=	[Total mass of ice formed in nth hour– Mass of ice formed in (n-1) hour] (kg)
Latent heat of ice per kg (L)	=	335000 J/kg

Q_{latent}	=	Latent heat removed from water to form ice (J/s)
	=	$[(M_i \times L) \div 3600]$
A	=	Heat transfer area at average diameter of ice (m^2)
	=	$[\pi \times [\text{diameter of tube} + (\text{diameter of ice with tube} - \text{diameter of tube}) \div 2] \times \text{length of tubes}]$
T_{bi}	=	Initial temperature of bulk water in thermal storage at t = 0 hour (°C)
T_{rf}	=	Evaporating temperature of R-22 at t = 0 hour = (°C)
T_{ri}	=	Evaporating temperature of R-22 at t = 1 hour = (°C)
T_{bf}	=	Final temperature of bulk water in thermal storage at t = 1 hour = (°C)
ΔT_1	=	$T_{bi} - T_{ri}$ = (°C)
ΔT_2	=	$T_{bf} - T_{rf}$ = (°C)
LMTD	=	Logarithmic Mean Temperature Difference (°C)
	=	$(\Delta T_1 - \Delta T_2) / \ln(\Delta T_1/\Delta T_2)$
U	=	Overall heat transfer coefficient (W/m^2 °C)

2.6 Energy Analysis of System

Total energy consumption (kWh) for 300 L of raw milk in OFMC and 980 L of raw milk in CMC was measured using energy meter (Make: Baroda Electric Meters Limited). Energy meter was installed at the main electricity input to the OFMC and CMC. The total electrical energy consumed in milk cooling during evening and morning including ice formation for OFMC was compared with the CMC. The energy consumed per litre of milk cooling was calculated by dividing total energy consumption of the system with the total quantity of milk cooled during evening and morning. The cooling cost of raw milk cooled from 34°C to 4°C for both the system was calculated as follows

> Cost of cooling (₹ /litre)= Energy consumed (kWh) in cooling per litre of milk × Electricity cost per unit (₹ /kWh)

3. RESULTS AND DISCUSSION

3.1 Performance of Milk Cooling System

Performance evaluation of milk cooling system was carried out with respect to rate of raw milk cooling, heat transfer analysis and COP.

3.2 Rate of Raw Milk Cooling in CMC

Cooling and collection of raw milk took place simultaneously during evening and morning as the cows were milked in batches. The cows of higher yield were milked first followed by the cows with the lower yield. The refrigeration unit of CMC was switched on once the 10% volume of rated capacity (1000 L) of BMC filled with milk during evening. The drop in temperature of raw milk per unit time during cooling was affected by heat removal capacity of refrigeration system, milk volume in contact with heat transfer area and volume of milk added to the CMC. It took about 2 h and 45 minutes to cool 480 L of raw milk from 34°C to 4°C during evening milk collection and cooling in CMC. The temperature of raw milk was maintained at 4°C overnight.

During morning, milk cooling and collection took place simultaneously. The fresh raw milk from morning milking was added intermittently into previous day raw milk kept at 4°C in BMC. The total collection and cooling time for 980 L (480 L evening + 500 L morning) of blend raw milk in the morning was 3 h and 50 minutes. Initially, temperature rise in raw milk was observed in BMC. This was due to the higher milk volume from high yield cows added into BMC at the beginning in morning. In addition to this, the bulk temperature of milk increased due to more quantity of milk added to BMC. The temperature of blend milk in BMC during morning increased from 4°C to 11.2°C within initial 1 h and 30 minutes. The temperature of raw milk was decreased then after in morning. It took about 2 h and 20 minutes to reduce raw milk temperature from 11.2°C to 4°C in BMC during morning. Though the collection of raw milk took place during initial 2 h and 30 minutes, the temperature drop of blend raw milk in BMC was due to milk added at very low volume flowrate from low yield cows towards the later stage of milking.

3.3 Rate of Raw Milk Cooling in OFMC

Raw milk collection was carried out immediately followed by cooling process. In the evening milk cooling process, 150 L of milk was cooled from 34°C to 4°C in OFMC. Raw milk was first cooled to 4°C through plate cooler followed by final storage at 4°C in cooling cum storage tank. In the next day morning, another 150 L of raw milk cooled to 4°C through plate cooler was added to previous day evening's raw milk at 4°C in cooling cum storage tank. Cooling of raw milk during evening and morning was completed within 30 minutes through plate cooler followed by final storage in cooling cum storage tank.

3.4 Heat Transfer Analysis of OFMC

Heat transfer is an important parameter affecting the cooling rate at which the milk is cooled within the stipulated time. Faster cooling of raw milk requires higher heat transfer rate compared to slower one. This implies that the size of the components in terms of effective heat transferring area can be optimized based on the requirement of cooling process. The overall heat transfer coefficient takes in to account the conduction and convective heat transfer occurring between equipment wall and flowing fluid. It is the amount of heat transferred per unit time per meter square surface area per degree difference in temperature between the fluids. The higher log mean temperature difference between two fluids means lower flow rate of both the fluids is required or lesser surface area can perform the required heat duty at a given flow rate and temperature difference. U value of OFMC for different components is given in Table 1. The U value of plate cooler when milk cooled to 4°C was 872.03 W/m^2 °C. The average overall heat transfer coefficient for milk cooling in the evening and morning were 359.0 W/(m^2 °C) and 350.2 W/(m^2 °C) respectively. The higher average U value in the evening milk cooling compared to morning milk cooling was due to higher average temperature drop of milk per unit time. The average U value for thermal storage was 121.65 W/m^2°C. The ice to water ratio at the end of ice formation in thermal storage was 0.29.

Table 1. Overall heat transfer coefficient (U) of on-farm milk cooling system for milk precooled to 4°C

Component of on-farm milk cooling system	Average U (W/m^2 °C)
Plate cooler	872.03
Cooling cum storage tank	709.20
Thermal storage tank	121.65

3.5 Coefficient of Performance (COP) of a Thermal Storage System

The COP of a thermal storage system is a ratio of useful heating or cooling provided to work (energy) required. Higher COP equate to higher efficiency, lower energy consumption and thus lower operating costs. COP of vapour compression refrigeration system (R-22) during day time and night time ice formation is given in Table 2. The COP of the system ranged from 3.97 to 2.36 during day time ice formation and 4.34 to 2.47 during night time ice formation. The average COP of the system was higher during night time compared to day time. This was due to low average condensing temperatures during night time because of low average ambient air temperature. It was also found that COP of the refrigeration system decreased as time progressed during ice making process in day and night time. This was due to higher compressor work done required at low refrigerating effect giving progressive reduction in quantity of ice formed. The energy consumed during day time and night time ice formation was 3.7 kWh and 3.3 kWh respectively.

Mhundwa et al. [12] carried out comparative analysis of the coefficient of performance of an on-farm direct expansion bulk milk cooler. The study presented a comparative analysis on the Coefficient of Performance (COP) of a direct expansion BMC to establish its performance under the morning (AM) and late afternoon (PM) milking times. According to the study's findings, the COP of the AM milking time was greater (2.20) than that of the BMC's PM milking period (1.93). It was discovered that as milk volume increased, so did the COP, with the COP increasing by 12.61 per cent and 19.81 per cent for the AM and PM milking times, respectively, at the peak period with high milk volumes. Despite this, the BMC's performance was directly influenced by changes in ambient temperature. The AM milking time was shown to have greater COP values than the PM milking time for both off-peak and peak periods. The higher volume of milk extracted from the cows was attributable to the low ambient temperatures and increased volume of milk extracted from the cows.

3.6 Electrical Energy Analysis of OFMC

Energy consumption for raw milk cooled to 4°C in OFMC is shown in Table 3. Total energy consumed for milk cooled at 4°C in morning and evening were 4.3 kWh and 4.8 kWh, respectively. The total energy consumed in evening milk cooling was higher compared to morning milk cooling due to more energy consumed by thermal storage system in ice making for evening milk cooling. Refrigeration system of thermal storage was operated twice in 24-hour time. Ice was formed during day time for evening milk cooling and during night time for morning milk cooling. Less energy in ice formation during night time was due to low average condensing pressure and temperature of R-22. The total energy consumed for 300 L of raw milk cooled at 4°C was 9.1 kWh.

According to Nejtek et al. [13], flat plate milk coolers, could save a significant amount of money by reducing the amount of electricity required for cooling. Other presumed benefits include lower cost of the cooling system maintenance and repairs due to lower load, longer service life of the entire system, positive impacts on the quality of milk in terms of rate of its cooling down to the required temperature. Hence, considerable power cost reduction is possible if flat-plate coolers are used in milk cooling.

3.7 Electrical Energy Analysis of CMC

Energy consumption in CMC is shown in Table 4. Energy consumed during evening and morning milk cooling for 480 L and 500 L of milk were 17.76 kWh and 18.50 kWh respectively. Compared to evening, energy consumed in morning milk cooling was higher due to higher operating time of BMC. During morning milk cooling, maximum bulk temperature of raw milk was 11.2°C because fresh raw milk at 34°C from morning milking was mixed with previous day

Table 2. Coefficient of performance (COP) of refrigeration system (R-22) during day and night time ice formation

Time (hh:mm)	Evaporating		Condensing		COP
	Pressure (psig)	Temperature (°C)	Pressure (psig)	Temperature (°C)	
Day time ice formation (Energy consumed: 3.7 kWh)					
10:30	60	1.04	225	43.10	3.97
11:30	35	-10.98	236	44.98	2.59
12:30	35	-10.98	245	46.48	2.47
13:30	34	-11.55	250	47.30	2.36
Night time ice formation (Energy consumed: 3.3 kWh)					
21:30	60	1.04	210	40.42	4.34
22:30	34	-11.55	225	43.10	2.71
23:30	34	-11.55	239	45.59	2.50
00:30	34	-11.55	245	46.48	2.47

Table 3. Energy consumption in on-farm raw milk cooling system for milk precooled to 4°C in evening and morning

Process	Equipment	Temperature of raw milk (°C)	Operating time (h)	Energy (kWh)
Evening milk cooling (Quantity of milk: 150 L)				
Precooling using plate cooler	Milk supply pump	34 to 4	0.75	0.3
	Chilled water supply pump		0.75	0.7
Cooling using cooling cum storage tank	Chilled water supply pump	4	0	0
Milk agitation	Agitator of cooling cum storage tank		0	0.1
Ice-formation	Thermal storage system	NA	0	3.7
Total energy				4.8
Morning milk cooling (Quantity of milk: 300 L)				
Precooling using plate cooler	Milk supply pump	34 to 4	0.5	0.2
	Chilled water supply pump		0.5	0.7
Cooling using BMC	Chilled water supply pump	4	0	0
Milk agitation	Agitator of cooling tank		0	0.1
Ice-formation	Thermal storage system	NA	0	3.3
Total energy				4.3

NA: Not applicable

Table 4. Energy consumption in control raw milk cooling system

Particulars	Temperature of milk (°C)	Quantity of milk (L)	Energy (kWh)	Total energy (kWh)
Evening milking	34 to 4	480	17.76	36.26
Morning milking	11.2 to 4	980	18.50	

evening milk at 4°C temperature in BMC. The total energy consumed for cooling of 980 L of raw milk was 36.26 kWh.

3.8 Cost Calculation for Cooling of Raw Milk by OFMC and CMS

Electrical energy consumption and cooling cost per litre of milk in OFMC and CMC is given in Table 5. When cost of electricity considered at ₹ 9.7 per kWh, cooling cost per litre of milk for OFMC and CMC were ₹ 0.2939 and ₹ 0.3589, respectively. The energy consumed in CMC was higher than the OFMC.

Table 5. Energy and cooling cost per litre of raw milk

Type of milk cooling system	Energy (kWh/L)	Cooling cost* (₹/L)
Control milk cooling system	0.0370	0.3589
On-farm raw milk cooling system	0.0303	0.2939

**Cost of electricity = ₹ 9.7 per unit*

Murphy et al. [14] investigated quick milk cooling management while altering the amount of water and energy used. The system consisted of a pre-cooler in the first stage that utilised ground water as a cooling medium and an ice bank that provides ice chilled water for the second cooling stage. It was observed that selection of low temperature pre-cooling set points resulted in larger volumes of ground water being consumed in the first stage per unit milk in comparison to the selection of higher temperature set points (three times higher). Low pre-cooling temperatures, on the other hand, resulted in lower ice storage use and, as a result, lower power usage. It was reported that the developed system has potential cost reductions of up to 34.5 per cent through the selection of the ideal water flow rates.

Rajaniemi et al. (2017) examined the electric energy consumption of milking process on dairy farms and to evaluate the methods to improve the energy efficiency. On three dairy farms in Southern Finland, the electricity consumption of the milking process was measured, and it ranged from 37 to 62 Wh kg-1 milk. Milk cooling and cleaning water heating were shown to have the highest potential for energy savings. Even basic methods, such as putting the refrigerated system's condenser outside, might save milk cooling's energy use by 30 per cent.

4. CONCLUSIONS

On-farm raw milk cooling system (OFMC) consist of storage cum cooling tank, plate cooler, milk, chilled water supply pumps and thermal storage system. For the raw milk, time taken to reach to 4°C from 34°C was lower in OFMC than conventional system. Cooling of raw milk using OFMC saves energy considerably than control. Hence, low processing cost with better quality raw milk can be achieved by utilizing OFMC compared to bulk milk coolers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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