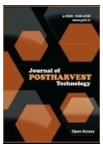

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RESEARCH ARTICLE

Quality analysis of milk stored in vertical chiller coupled with solar photovoltaic system

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ABSTRACT

The present study was carried out to know the quality of milk stored in solar-based milk chiller. A 40 lit capacity of milk chiller was tested with no load and full load condition. In full load, milk was loaded and the temperature of the milk was recorded for every 10 min of interval. Quality analysis of raw milk, as well as chilled milk for the duration of 0, 12, 24, 36 and 48h, were analysed. The average initial temperature of raw milk was found to be 34.4°C. The milk temperature in the chiller was reduced to 4ºC in 100 min, which was within the recommended milk cooling time after milking (WHO). The final temperature of the milk varied depending on the loading of the milk as well as the influence of the agitation. There were no significant variations observed in the quality parameters of raw and chilled milk. The developed solar photovoltaic milk cooling unit may be recommended for small use where electricity is the main constraint.

Keywords: Milk chiller, fat, SNF, acidity, milk quality

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INTRODUCTION

Milk is highly perishable complete food with high water activity near neutral pH (6.4-6.7) and nutritional composition make milk suitable medium for microbial growth (Silva et al., 2010; Sadhu, 2018). It is consumed directly or used in preparation of many food items such as cake, pies, pastries, peda, khoa and so on to provide specific functional (Sadhu, 2018). Generally, cow milk contains of 87.7 % water, 4.9 % lactose, 3.4% fat, 3.3% protein, and 0.7% ash (Constantin and Csatlos, 2010). Fat present in milk is highly digestible and also a rich source of energy containing different fatty acids in a large scale compared to any other food items does. Milk protein contains all essential amino acids in well proportions. Lactose is the only naturally available sugar

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found in milk that plays an important role for the nourishment of brain tissue. Moreover, it contains the available quantity of different vitamins and mineral for body growth (Sadhu, 2018).

Globally milk cooling is the most widely chosen method of milk preservation. Cooling of milk to about 4°C within two hours inhibits the growth of bacteria that spoils the milk (Sur et al., 2020). Moreover, inadequate refrigeration, handling practices, and temperature abuses occurring during any stage of the cooling process can cause unexpected loss of quality and a significant decrease in the expected shelf-life, due the rapid growth of bacteria (Koutsoumanis et al., 2006). Temperature significantly affects the growth of microorganisms and deterioration of the milk, unless stored at controlled low temperatures (Chandler & McMeekin, 1985). The microbiological quality of milk depends on both the types of bacteria present in the milk and the number of microorganisms (Sadhu, 2018). The objective of this study was to investigate the effect of milk storage temperature and stirage time on the microbial quality of bulk milk cooler when fresh milk is added to the bulk tank daily.

MATERIALS AND METHODS

The experiment was conducted at Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University and Technology, Udaipur, Rajasthan where all essential utilities are available to conduct the experiment.

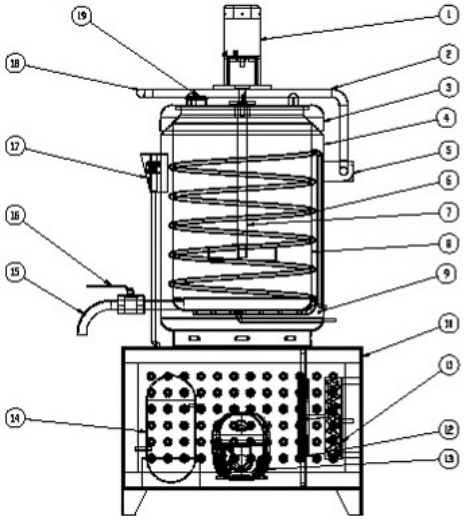

Fig. 1 (a)

Fig. 1 (b)

(1) Motor Lid joint (2) Lid (3) Outer shell(4) Hinge (5) Coil (6) Agitator rod(7) Cooling chamber (8) Insulation (9) Stand (10) Condenser (11) Fan (12) Compressor (13) Reservoir (14) Outlet valve (15) Outlet (16) Control panel (17) Lid handle (18) Inspection window

Fig 1. (a) Schematic and (b) Photographic representation of milk chiller

Experimental set up

A solar based milk chiller was used for the investigation as shown in Fig 1. The system is comprises of a milk tank made of food-grade standard stainless steel sheet (SS-304) with storage capacity of 40 lit, polyurethane (PUF) insulation material, an agitator, an adaptive control unit, photovoltaic panels, storage batteries, and an inverter. A copper tube of length 1400 mm and diameter 9.525mm was wound over the milk tank. The entire unit was insulated with 40 mm polyurethane foam. Forced convection air-cooled condenser with tube diameter of 10.1 mm and a fan (blade size-2032 mm, motor-45 W) was used. The unit was worked on vapour compression refrigeration system coupled with a solar panel that harness the solar radiation with the help of an adaptive control unit and transfers it to a storage battery connected to a refrigeration unit. A pair of batteries (150 Ah, 12 V) was connected to make power available for continuous milk cooling for a longer period during unavailability of solar light or in night. A digital scale was installed at the wall of the chiller to set the desired temperature. Raw milk having approximately temperature of about 34.4°C after milking was transferred into the chiller unit to cool down the temperature to 4°C. A schematic view solar based milk chiller is presented in Fig 1.

Preparation and testing of the milk samples

The raw milk of cow was collected from local dairy farm of Udaipur (Rajasthan) just after milking the milk was collected in a sterilized clean stainless steel container and transferred to chiller with min time laps (Fig 2). A raw milk sample (100 mL) from whole sample was taken for quality analysis. Once the milk inside the chiller reached to desired temperature of 4ºC, the quality analysis of the milk was done at every 12 h of interval up to 48 h. Before sample collection for analysis, the milk was agitated at 25 rpm for 10 min to avoid milk separation (O'Connell et al., 2016). Samples were collected through the viewing inlet on the top of the bulk milk cooler using a sanitized milk sample dipper (50mL), in accordance with the procedure suggested by Graham (2004). The cooling temperature, time, and volume of milk displayed on the milk cooler were manually recorded.

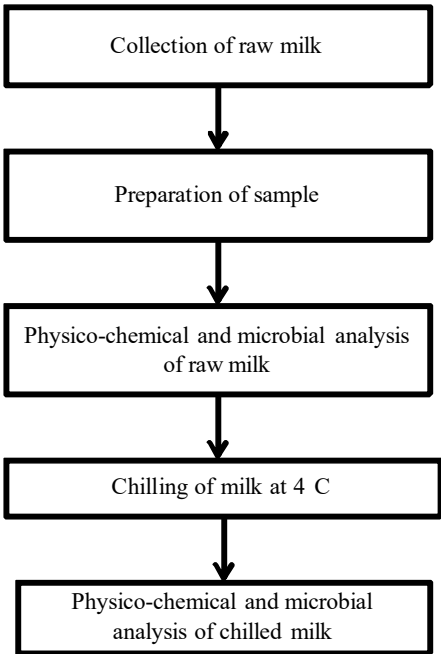

Fig. 2: Flow diagram of milk chilling and quality analysis

Chilling of milk

The experimental trials were conducted in the month of May, 2022 to know the cooling performance of the solar milk chiller. The average solar intensity in the month of May, 2022 was recorded between 378 to 1089 W/m^2. The ambient air temperature varies thorough out the day and hence timings were kept the same for conducting trials for better comparison of the performance data. The surface area of the milk tank involved in the heat transfer depends on the quantity of milk loaded in the bulk milk cooler. Therefore, a milk loading of 40 litres was considered for operation. The electrical parameters and operating conditions of cooling unit were measured during the experimental trials. Three replications were done for each data to get the accurate average result of each parameter.

Properties of milk

The physic-chemical properties of raw and chilled milk was analysed to know any variation in the quality of milk. The following parameters were analysed during the study. All determinations were carried out as per methods suggested by AOAC (2005). The moisture content was determined by the difference between the known weight of milk sample and the determined weight of the total solid after evaporating the water of the milk sample from a hot dish. The pH measurement of the sample was measured using digital pH-meter (Phoenix, PH-035) calibrated with buffer solution of pH 4 and 7. Titratable acidity was analysed by titrimetric method estimated by method described by Gakkhar et al., (2015), and expressed as per cent of lactic acid. Specific gravity, solid not fat, and viscosity were determined by standard methods (AOAC, 2005).

The protein content in the sample was determined by Kjeldahl method in terms of nitrogen. The obtained value of nitrogen was multiplied by conversion factor of 6.38 (AOAC. 2005). Total solid content in the milk was determined by FSSAI (2012) method. The total ash content of milk was estimated as per AOAC (2005) using muffle furnace, and was expressed in per cent. Other minerals presents in the sample were also analysed using FTmilko Scan machine (Fig. 3) following standard methods.

Fig 3: FTmilko Scan machine

Microbiological analysis

Standard plate count was assessed daily in triplicates for the processed and control samples for period of ten days. The samples were analysed for standard plate count following by the method described by American Public Health Association (APHA, 1998).

RESULTS AND DISCUSSION

Chilling of milk

The milk chiller was loaded with milk and the system was operated with solar power during day time, thereafter switched to battery to continue the operation during unavailability of solar light. The average initial temperature of milk was measured to be 34.3ºC in all the trials. The overall average cooling load of milk was 0.360 kW. From Fig.3, it is clear that the average time required to achieve a temperature of 4ºC was found to be 100 min. The system was operated for 24 h to maintain the milk temperature of 4ºC. The temperatures of evaporator and suction line were also observed to fall when the compressor was running and then raised during the cut-off period where as the temperature of condenser and discharge line were rise during the on-cycle. The compressor body temperature was also measured and it was found that to be 41ºC and steadied which shows the continuous heat is leaking from compressor. The thermostat cut-in and cut-out happens according to the temperature of milk in the tank. After completion of full load test with milk the warm up test was also conducted to know that storage duration of tank. The milk temperature in the tank was about 4ºC and it was remained below 10ºC for upto 3 h as shown in Fig. 4 which means insulation thickness and room condition both were well for the milk storage.

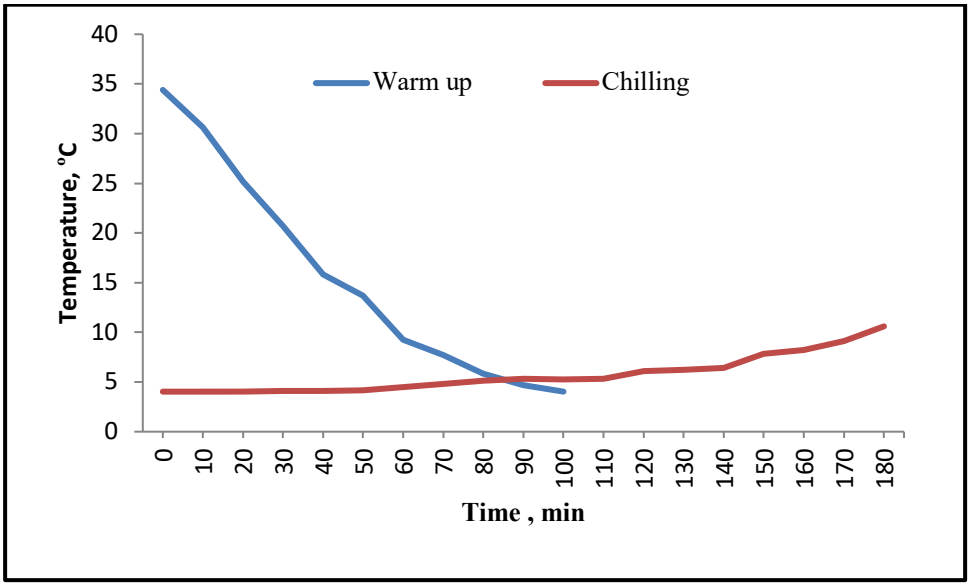

Fig. 4: Variation of temperature during cooling and warm up condition

Physico-chemical properties of raw milk

The physical and chemical properties of fresh milk were analysed before the milk was chilled which were presented in the Table 1. The physical properties of the fresh milk samples were studied after collection. The colour of the sample was white and had normal flavour. Roy et al., (2017) reported that the flavour of the milk produced hygienically was normal. The milk sample collected from dairy farm had normal texture (free flowing liquid). The specific gravity of normal milk sample ranged from 1.03 to 1.05 g/ ml with average value of 1.04 g/ml which was similar to result obtained by Tamime (2009) and Roy et al., (2017). The observed titratable acidity of fresh milk sample was 0.24% which nearly equal to the standard range of 0.12 to 0.14 % reported by Sukumar (1980).

The present study found 3.95% fat content in the fresh milk which was almost equal to standard and lower than Roy et al., (2017). Further, in accordance with European Union quality standards for unprocessed raw milk, protein content should not be less than 2.9% (Tamime, 2009). The study found 3.77% protein content which greater than the standard and also greater than result (3.2±0.11%) obtained by Debebe (2010) and lower than Fikrineh et al., (2012) and Roy et al., (2017) who observed protein content of 3.46±0.04% and 3.4%, respectively. The observed ash content under the study was 0.68% which was lower than all the mean values of ash content of raw milk samples of Roy et al., (2017).

Table 1: Physico–chemical properties of raw milk

Properties	Parameters	Values			
		Min.	Max.	Average	SD
	Colour		White		
	Flavour		Sweet aroma		
	Texture		Free flowing		
Physical	Specific Gravity	1.03	1.05	1.04	0.017
	Viscosity, cP	1.33	1.35	1.34	0.010
	Density, g/m^3	1028	1031	1030	0.010
	pH	6.75	6.78	6.76	0.009
	Acidity, %	0.123	0.125	0.124	0.001
	Fat, %	3.84	3.96	3.95	0.010
	Protein, %	3.76	3.78	3.77	0.010
	Ash, %	0.66	0.69	0.68	0.015
Chemical	Solid-not-fat, %	8.46	8.49	8.47	0.015
	Total solid, %	12.15	12.23	12.18	0.041
	Water, %	87.77	87.85	87.82	0.042
	Lactose , mg/L	4.62	4.66	4.64	0.021
	Maltose , mg/L	0.11	0.13	0.12	0.012

Other minerals like lactose and maltose was in the range of 4.62 to 4.66% and 0.11 to 0.13%. The values of lactose and maltose were in the range.

The value of observed total solid was 12.18% which was greater than the reported values of Bille et al., (2009) and Roy et al., (2017) who found TS of 12.33% and 12.40% respectively. According to European Union quality standards for unprocessed raw milk, value of solid-not-fat content should not be less than 8.4 (Tamime, 2009). The recorded value of solid-not-fat content was 8.47% which was near to standard value and also the finding of Bille et al., (2009) and Roy et al., (2017) which was 8.7% and 8.8% respectively and lower than Fikrineh et al., (2012) who reported a solid-not-fat content of (9.10%). Quantitatively, the predominant component of milk is water (approx. 87.6%) and total dry matter (total dry extract) is approx. 12.4 % which is the nutritious milk (Roy et al., 2017). The study found 87.82% water content which was nearly same with Roy et al., (2017).

Physico- chemical properties of chilled milk

The physical and chemical properties of chilled milk at 4ºC were analysed at 0, 12, 24, 36 and 48 of interval as presented in the Table 2. The colour of the sample was white and had normal flavour at throughout storage 48 h of storage. No significant increase in pH values was observed after 48 h of storage. The pH value was also agreement with result obtained by Schmutz and Puhan (1981). The average value of pH during the storage was ranged from 6.75 to 6.78 at 0 to 48 h of storage. A very

insignificant variation between pH of milk from 0 to 48 h of storage time was observed. It is concluded that milk stored at 4ºC for 48 h can be treated as safe. This result was agreement with result obtained by Malacarne et al., (2013).

Table 2: Mean value of physical and chemical properties of chilled milk

Properties	Parameters	Mean values				
		0 h	12 h	24 h	36 h	48 h
Physical	Colour	White	White	White	White	White
	Flavour	Sweet aroma	Sweet aroma	Sweet aroma	Normal	Normal
	Texture	Free flowing	Free flowing	Free flowing	Flowing	Flowing
	Viscosity	1.33	1.33	1.34	1.34	1.38
	Specific gravity	1.03	1.04	1.04	1.04	1.05
	Density	1028	1031	1031	1032	1032
	pH	6.75	6.76	6.75	6.77	6.78
	Acidity	0.123	0.123	0.124	0.126	0.127
Chemical	Fat, %	3.95	3.96	3.95	3.96	3.97
	Protein, %	3.77	3.77	3.77	3.65	3.77
	Ash, %	0.68	0.68	0.68	0.69 %	0.69
	Solid-not-fat, %	8.46	8.47	8.48	8.47	8.48
	Total solid, %	12.15	12.16	12.17	12.18	12.20
	Water, %	87.82	87.81	87.85	87.84	87.81
	Lactose , %	4.67	4.68	4.64	4.63	4.65
	Maltose, %	0.12	0.12	0.12	0.13	0.12

The titratable acidity of chilled milk ranged from 0.123 to 0.127. A very insignificant variation in titratable was observed. This result also agreement with result obtained by (Malacarne et al., 2013). The concentration range of total solids was from 12.15% to 12.20 as presented in Table 2. The amount of fat and SNF content in the chilled was found in the range of 3.95 to 3.97% and 8.46-8.48%, respectively for 0 to 48 h of storage. The specific gravity of all the milk samples were found to be 1.02 to 1.05. Slight variations in specific gravity were found due to the water content present in the sample (Rehman and Salaria, 2005). The results show that values for the total solids and fat in all the milk sample are in good agreement with the reported literature ((Malacarne et al., 2013).

Microbiological analysis of chilled milk

The standard plate count of milk stored at 4ºC for different intervals were analysed and depicted in Fig 5. The observed value of SPC in the chilled milk was found to be 2.31×10^5, 2.38×10^5, 2.49×10^5, 2.43×10^5 and 2.46×10^5 cfu/ ml for 0, 12, 24, 36, 48 h of storage period. It can be concluded that the storage period had significant ($p<0.01$) effect on SPC in cooled milk. The average SPC in all the samples was found within the recommended range of safe milk (Bureau of Indian Standard (BIS, 1997). Also, the SPC value was drastically increased thereafter making it unsafe for consumption as per FPA (1954). The results of present investigation are in agreement with those recorded by Agarwal et al. (2018).

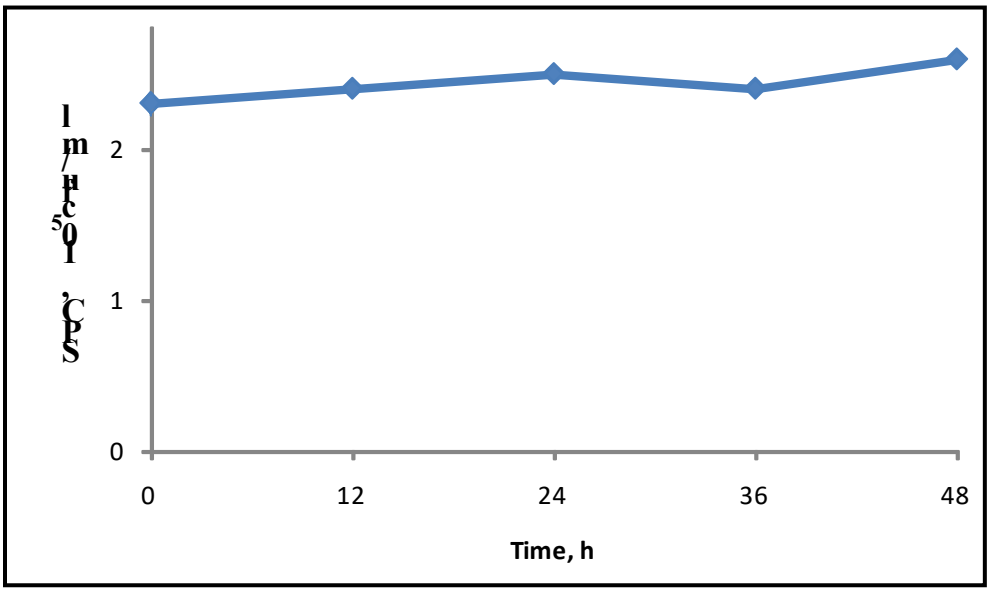

Fig 5: Standard plate count growth (cfu/ml) in milk during storage

CONCLUSIONS

The present study includes the chilling of milk in vertical milk chiller operated with solar PV panel. The cooling time required to reach the lower temperature of 4°C was 50 min and 100 min for no load and full load condition. The physico-chemical properties of raw and chilled milk were within the recommended range. There was no significant variation in quality of chilled milk stored at 4ºC for 48 h was observed. These results were similar to standard safe values of milk. The system performance was found to be satisfactory for the milk storage. There was insignificant variation in microbial count of chilled milk was observed.

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