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# Development and Performance Evaluation of Solar Based Milk Pasteurizer

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**ABSTRACT:** The milk is an important part of diet throughout life. The milk is a perishable foodstuff because it is an excellent medium for the growth of microorganisms which cause spoilage. Pasteurization method is proven technique to prevent spoilage of milk and increase its shelf life, energy is needed conventional pasteurizing units also required high initial investment for equipment. The uninterrupted power supply makes it difficult to use electrically operated processors for milk treatment. Utilization of available solar energy may be a logical solution to solve the energy problem caused by scarce fuels and electricity. Thus efforts are made to utilize pasteurizing the milk. Developed unit of shell and tube type milk pasteurizer was coupled with FPC solar water heater and hot water from water heater was used as heating medium for milk. Developed unit was tested for different flow rate of input hot water. The system was found to be efficiently working with input hot water flow rate of 300 ml/min. Also microbial count of pasteurized milk from developed unit was found to be within acceptable range.

**KEYWORDS:** Flat plate collector, milk pasteurization, solar based milk pasteurizer, microbial count.

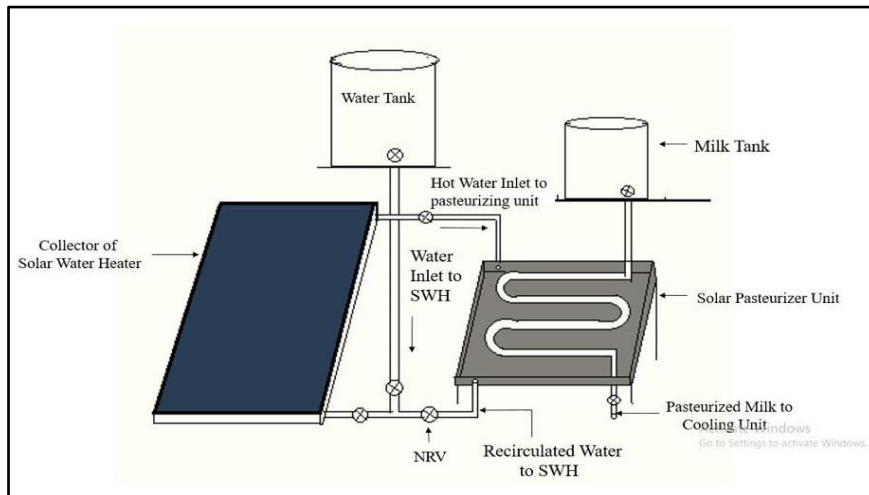
## I. INTRODUCTION

The milk and its products are important in human nutrition from childhood till old age. It is used as an important part of diet throughout life. Milk production and processing provide employment, not only to people who work on dairy farms or in dairy plants but also to the whole communities, from upstream, e.g., inputs and services providers to downstream, e.g., marketing of finished products. Dairy cooperatives have played a very significant role in the procurement, processing and marketing of milk and dairy products [4]. The milk is a perishable foodstuff because it is an excellent medium for the growth of microorganisms which cause spoilage. Heating of milk to the specific temperature for specific period of time, leads to kill harmful microorganisms which increases the shelf life of milk. Milk being a complete food, it is a highly nutritious growth medium for microorganisms, which may include beneficial organisms (e.g., lactic acid bacteria) as well as numerous spoilage organisms (e.g., Gram-negative psychrotrophs) and bacterial pathogens (e.g., *Salmonella*, *Listeria*) [2]. Pasteurization of milk refer to the process of heating every particle of milk to a specific temperature, holding it at the same temperature for specific duration (time) and followed by rapid chilling to less than 7°C. The actual definition of pasteurization is; the heating of milk to a specific temperatures for a specific time to reduce undesirable enzymes and bacteria to negligible levels. It is important that pasteurization is function of time and temperature not just temperature [5]. Though, pasteurization method is proven technique to prevent spoilage of milk and increase its shelf life, energy is needed conventional pasteurizing units also required high initial investment for equipment. Small scale milk producers could not afford this kind of technique for treatment of milk. Utilization of available solar energy may be a logical solution to solve the energy problem caused by scarce fuels and electricity. It is free and does not have any negative impact on the environment. The results had shown that there was tremendous scope of utilizing solar energy in dairy processes such as pasteurization of milk [6]. The abundance of solar energy paired with the concept of milk pasteurization promotes a new solution to increase storability and shelf life of

unsafe milk. People in sun-rich areas of developing countries often cannot afford modern fuels and suffer from ever-increasing fuel wood shortages. The use of sunshine to cook and pasteurize contaminated water and milk could provide a new approach to these debilitating problems [8]. This solution has the following advantages: energy conservation, ensures a better human health in remote areas, address the problem of energy at reduced cost as the operative cost of such energy is negligible and an innovative use of solar energy application[1] carried out performance analysis of solar milk pasteurizer system with the aid of flat-plate collector. Their prime concern was to develop innovative design of solar pasteurizer for the individual dairy producers who do not have the availability of electricity and gas.[7] have carried out experiments on low-cost solar milk pasteurizer with the help of flat-plate solar water heating collector and 1.5 mm thick stainless steel milk vat and tested in climate conditions of Kenya for 40 l of raw milk. They used milk container of capacity around 80 l and 50 mm wide hot water jacket insulation. They have found that the present low-cost solar milk pasteurizer with 40 l milk required approximately 1.360.5 h with solar intensity around 700–1000 W/m<sup>2</sup> [3] fabricated low-cost solar concentrator (without sun tracking) for pasteurizing of goat milk for cheese production. They used Fresnel type solar concentrator with the focal distance of 55 cm and 6.6 kg of weight for solar pasteurization and fabricated in a home. They also used the homemade boiler, which was used to heat the water in the concentrator inside the Pyrex breaker. They have carried out a series of experiments with different quantity of milk for pasteurization. After a series of tests, they have found that Fresnel type low-cost concentrator achieved pasteurization of 10 l milk about 1 h of a time interval and it has energy payback time around 8 years.[9] have fabricated a solar milk pasteurizer from standard appliance shipping cardboard with multiple layers of the regular aluminum foil glued onto cardboard which was insulated with a large cardboard box which contained the rectangular area and a removable glass window has been used. The inner box having volume (52.5×24×36) cm covered on both sides with aluminum foil. A metal tray painted black. This experiment was done on temperature ranging from 65 to 75 °C.

## II. MATERIALS AND METHODS

Development and Performance Evaluation of Solar based Milk Pasteurizer which was carried out at the Department of Electrical and Other Energy Sources, CAET, DBSKKV, Dapoli. The laboratory testing and field evaluation was carried out at Energy Park, Department of Electrical and Other Energy Sources, CAET, Dapoli. Existing solar flat plate collector is coupled with milk pasteurization unit. Outlet hot water of flat plate collector water heater is used as heating medium for milk in pasteurization unit.



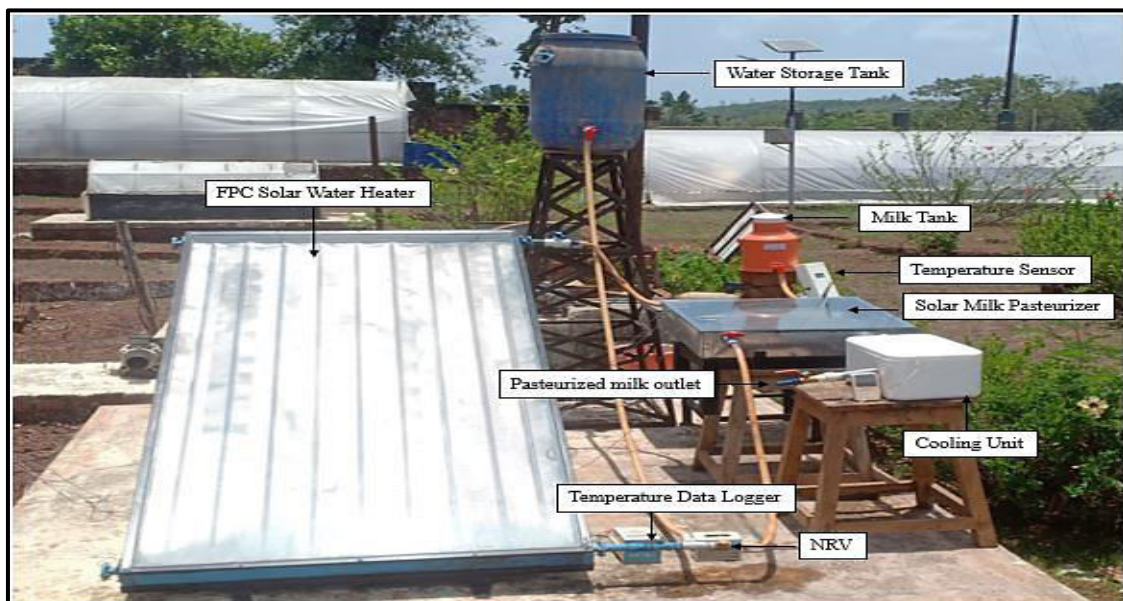
**Fig. 1 Components of FPC solar water heater based pasteurizer unit**

The flat plate collector solar water heater with collector area of 2 m<sup>2</sup> was used to provide input hot water to the pasteurization unit. The specifications of flat pate collector solar water heater are listed in table 1.

**Table 1: Specifications of flat pate collector solar water heater**

Sr. No.	Parameter	Specification
1.	Type	Flat Plate Collector Type
2.	Capacity	150 L
3.	Gross area of collector plate	2 m <sup>2</sup>
4.	Length of collector	2 m
5.	Width of collector	1 m
6.	Casing	Wood and Aluminium sheet
7.	Thermal conductivity of plate material	385 W/m.K
8.	Plate Thickness	0.7 mm
9.	Absorptivity of plate	0.95
10.	Thickness of the glass	4 mm
11.	Transmittance of glass	0.95
12.	Glass cover emissivity	0.85
13.	Insulation thickness	50 mm
14.	Thermal conductivity of Insulation	0.044 W/m.K
15.	Diameter of the riser tube	12.5 mm
16.	Diameter of the Header tube	25 mm

Thermal analysis of available flat plate solar water heater was carried out and based on results obtained shell and tube type solar milk pasteurizer was developed. Food graded serpentine shape stainless steel milk tube of length 3 m fixed in the box of 0.60 × 0.50 × 0.10 m<sup>3</sup>. The box was filled with hot water from solar water heater so that serpentine shape milk tube will be fully immersed in hot water. The glass wool insulation of thickness of 0.025 m was provided to the box. The box was painted black from inside to gain maximum solar radiations. The glass of thickness 5 mm was used as a top cover on box. Volume of milk inside tube for each batch was 1 L. Milk inside tube get heated due to the heat transfer from hot water to milk tube. Figure below shows the pictorial view of solar milk pasteurizer and experimental setup for solar milk pasteurizer coupled with flat plate collector type solar water heater.



**Fig 2: Pictorial view of Solar milk pasteurizer coupled with FPC solar water heater**

### Working of the system

The water stored in water storage tank at ambient temperature was fed to the inlet of flat plate collector through the inlet pipe. The hot water outlet from the flat plate collector was connected to the pasteurizer input. A flow control valve and water flow meter were connected between FPC and pasteurization unit to adjust the flow rate of hot water to the pasteurizer which was measured by water flow meter. The raw milk stored in the milk tank at ambient was



passed to the milk tube of pasteurizer through the pipe. The heat was transported from hot water in holding box to milk present in tube resulting in lowering the temperature of hot water. This used water with lower temperature was removed from water outlet of holding box and it was recirculated to flat plate collector so as to conserve energy and use waste heat. The fresh high temperatures hot water from FPC solar water heater was added continuously to the pasteurizer unit till the temperature of milk inside tube reach the pasteurization temperature of 72 °C. The temperatures of inlet hot water, bottom of holding box, milk inside the tube, water inside holding box, solar intensity were recorded at an interval of 10 min. After reaching the pasteurization temperature of 72 °C, milk was held for 15 second into the tube and then allowed to pass to the outlet. Microbial testing of pasteurized milk from solar milk pasteurizer was carried out later.

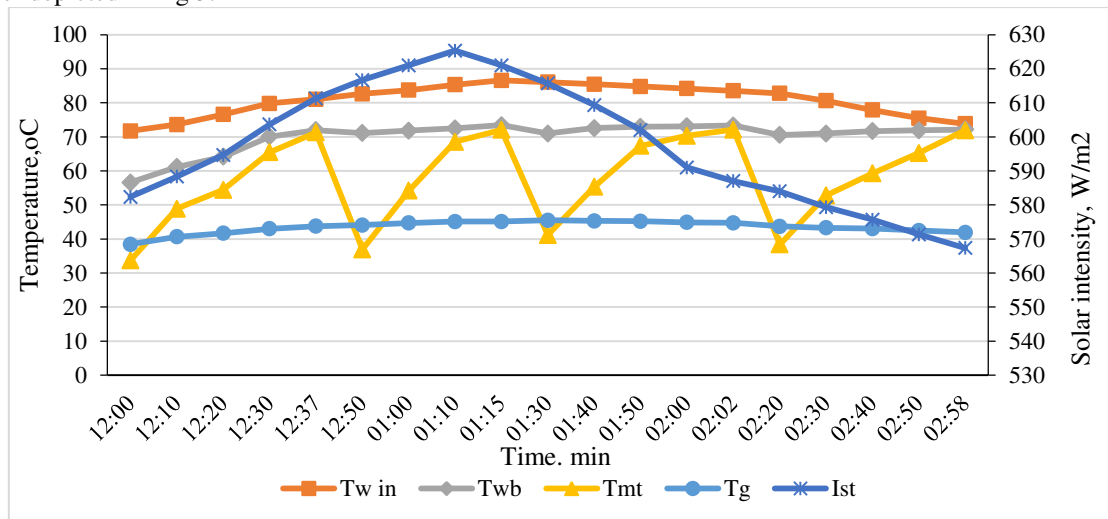
**Performance evaluation of pasteurization unit**

For performance evaluation of solar milk pasteurizer testing was carried out for different flow rate of input hot water in holding box. Three different hot water flow rates such as 200 ml/min, 250 ml/min and 300 ml/min. was chosen for experimental studies. The readings were taken during peak sunshine hour from 12 pm to 3 pm. The experimental set-up was instrumented to measure solar intensity, input hot water temperature, input milk temperature, milk temperature inside tube, water temperature inside holding box and glass cover temperature of solar based milk pasteurizer. Time required to reach pasteurization temperature inside milk tube for different flow rate was measured.

**III. EXPERIMENTAL RESULTS**

**Testing of solar milk pasteurizer with milk for different input hot water flow rate**

Temperature variation in solar pasteurizing unit for load testing for with milk for different flow rate of input hot water depicted in Fig 3.



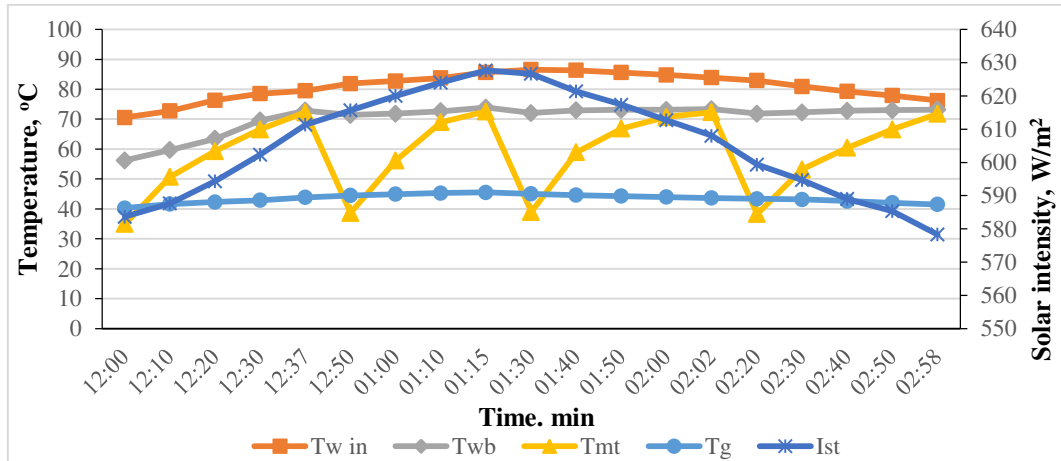
**Fig 3: Temperature variation with solar intensity and time inside the solar milk pasteurizer (Hot water flow rate- 200 ml/min)**

For load testing of pasteurizing unit with milk, milk tube was filled with buffalo milk up to its full capacity i.e. 1 L and then hot water was filled in holding box until tube was fully immersed in water. Initial temperature of milk and input hot water was 33.67°C and 71.7°C, respectively. Time required to reach pasteurization temperature for the first batch of 1 L of milk was 38 min. The milk was kept for 15 sec and then passed to cooling chamber. After completion of process next batch of milk was filled in to milking tube. Temperature of milk inside milk tube for second batch was initially at 36.93 °C and input hot water was 82.6 °C. Glass cover temperature and absorber temperature was found to be almost constant during while process. The time required for 4 batches of milk was 38 min, 27 min, 33 min and 41 min, respectively. Total time required for 4 L batch of water to reach pasteurization temperature 139 minutes during time interval of 12 PM to 3 PM for input hot water flow rate of 200 ml/min. The maximum solar intensity and input hot water temperature was recorded 625 W/m<sup>2</sup> and 86.6 °C at 1.20 PM. The time required to reach pasteurization temperature i.e. 72 °C was found less during second batch, that was due to input hot water temperature was higher during noon due to high solar intensity. The milk was cooled to 10 °C in the cooling chamber and sealed for further storage studied and investigation.



**Load testing of solar milk pasteurizer with milk for flow rate of 250 ml/min**

Temperature variation in solar pasteurizing unit for load testing for with milk for input hot water flow rate of 250 ml/min is depicted in Fig 4.

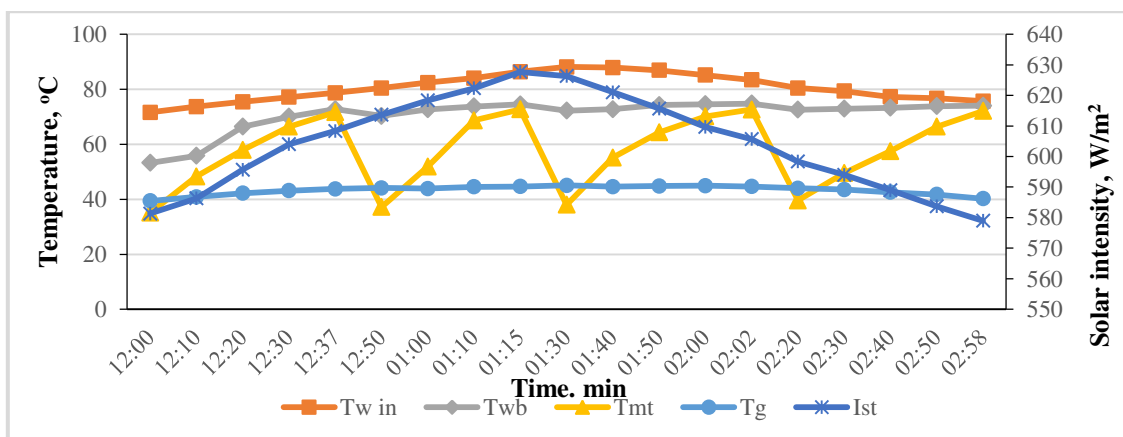


**Fig 4: Temperature variation with solar intensity and time inside the solar milk pasteurizer (Hot water flow rate- 250 ml/min)**

For load testing of pasteurizing unit with milk, hot water flow rate was kept constant at 250 ml/min. Initial temperature of input hot water and milk inside milk tube was 70.5°C and 34.98°C, respectively. Time required to reach pasteurization temperature for the first batch of 1 L of water was 36 min. Temperature achieved in milk tube after 36 min was 72.28 °C. First batch of milk was held for 15 seconds resident time in milk tube at given temperature and then milk was passed to the cooling chamber. After completion of process next batch of milk was filled in to milking tube. Input temperature of milk inside milk tube for next batch was 38.68 °C and input hot water was 81.9 °C. Glass cover temperature and absorber temperature was found to be almost constant during the process. Maximum solar insolation and maximum input water temperature was 628 W/m<sup>2</sup> and 86.6 °C, respectively at 1.30 PM. Time required for second, third and fourth batch of water to reach pasteurization temperature were 26, 33 and 40 minutes, respectively. Second and third batch of milk required less time to reach pasteurization temperature i.e. 72°C than first and fourth batch of milk due to input hot water temperature was higher during noon due to high solar intensity. Total time required for pasteurization of 4 L of water with input hot water flow rate of 250 ml/min was 135 min during time interval of 12 PM to 3 PM.

**Load testing of solar milk pasteurizer with milk for flow rate of 300 ml/min**

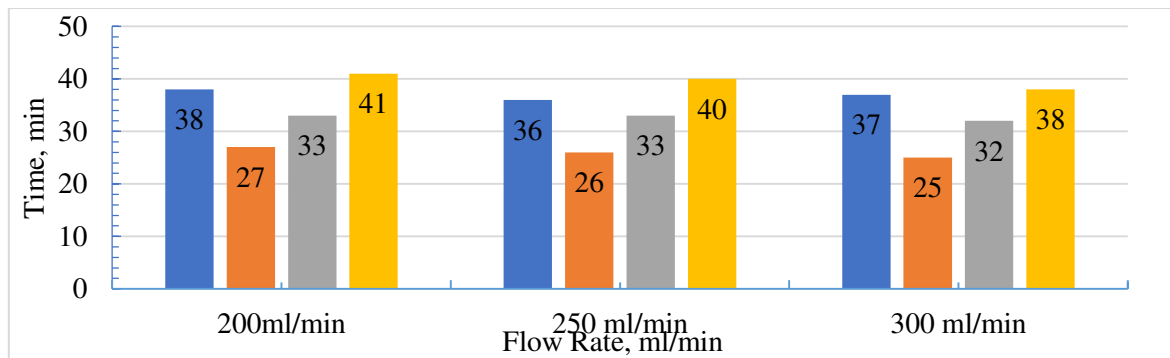
Temperature variation in solar pasteurizing unit for load testing for with milk for input hot water flow rate of 300 ml/min is depicted in fig.5.



**Fig 5: Temperature variation with solar intensity and time inside the solar milk pasteurizer (Hot water flow rate- 300 ml/min)**

The pasteurizer was tested for actual milk sample of 4 L quantity. Milk tube of pasteurizer was filled up to its full capacity of 1 L. Initially average input hot water temperature was 71.6 °C and average input milk temperature was 35.11 °C. The flow rate of hot input water from FPC was kept constant as 300 ml/ min. The time required to reach the first batch of milk to pasteurizing temperature was 37 min. After that batch of milk was held for resident time of 15 sec. in milk tube at constant temperature and then the milk was withdraw from milk tube and further passed to the cooling unit. Next batch of milk filled in the milk tube required about 25 min. to reach the pasteurization temperature. Similar procedure was carried out for next two batches and results obtained showed that average time required for Batch III and Batch IV was 32 min. and 38 min. Since the specific heat of milk is lower than water, time required for heating the milk to pasteurization temperature was also lower. Maximum solar insolation and maximum input water temperature was 628 W/m<sup>2</sup> and 88.1 °C, respectively at 1.40 PM. Results shows that total time required for pasteurization of milk batch of 4 L was 132 minutes with hot water flow rate of 300 ml/min. Time required for second and third batch to reach the pasteurising temperature was less than first and last batch due to high input water temperature was obtained due availability of high solar insolation.

Graphical representation of time required per batch for pasteurization of milk with respect to different flow rates of input hot water to pasteurizer unit is shown in fig.6.



**Fig 6: Comparative performance of solar milk pasteurizer for different hot water flow rates in load condition for milk**

The tests were carried out for three different flow rates viz. were 200 ml/min, 250 ml/min and 300 ml/min. It was observed that time required to reach the pasteurizing temperature was least for flow rate of 300 ml/min in comparison to other two flow rates due to higher input heat supply compared to other flow rates of input hot water. Time required for flow rate of 200, 250 and 300 ml/min was 139, 135 and 132 min, respectively. Though there was no larger difference between time required, noticeable time difference was observed when tested with large prototypes of developed unit of solar milk pasteurizer. Thus flow rate of 300 ml/min was found to be most effective and selected for pasteurization process.

#### IV. CONCLUSIONS

1. The performance evaluation of flat plate collector solar water heater resulted into maximum temperature of output hot water of 88.1 °C at the maximum available solar intensity of 621 W/m<sup>2</sup> at 1.00 hrs.
2. For load testing of solar milk pasteurizer with milk, total time required for pasteurization of 4 batches of milk was 139 min for the input hot water flow rate of 200 ml/min. Similarly for flow rates of 250 and 300 ml/min, time required was 135 and 132 min, respectively.
3. The input hot water flow rate of 300 ml/min was found to be most effective to achieve pasteurization temperature. Time required for pasteurization of four batches of milk with this flow rate was minimum i.e. 132 min. during peak sunshine hours of 12 pm to 3 pm, at average solar intensity of 603 W/m<sup>2</sup>.
4. From microbial testing of pasteurized milk sample from developed unit of solar milk pasteurizer it was found that average microbial plate count for pasteurized milk was 7225 SPC/ml of milk. Since microbial count of milk sample was 20000 SPC/ml, pasteurized milk from developed unit was acceptable and safe for consumption.
5. The extra hot water capacity of installed solar water heat can utilized by coupling with developed pasteurizing unit with small investment to pasteurize milk available at household level.



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