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RESEARCH ARTICLE

# Enhancing time availability for milk processing using thermal oil as solar heat reservoir

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**Abstract:** India is a world leader in milk production, with an annual production of 230.6 MT. Only 30 percent of milk is currently handled in the organized sector. A cheap source of reliable energy is needed to shift the unorganized sector to an organized sector, as dairy operations are energy-intensive. Solar energy is renewable, inexhaustible, promising, and abundantly available in India. In the literature, it was found that dairy operations such as sterilization of milk can be done using solar energy. However, the limited sunshine hours make it possible to handle only a limited quantity of milk day-to-day. This paper aims to discuss the performance evaluation of a solar heat reservoir to enhance the operational hours during the daytime when solar radiation is insufficient to provide the required energy to carry out the operations. It was found that by using the designed thermal reservoir, the working hours for milk processing were enhanced by 25 to 50 percent, depending on the ambient solar conditions.

**Keywords:** Farm processing; Heat exchanger; Milk; Renewable energy; Solar; Thermal

**Standard Abbreviations:** °C- degree Celsius; h- hour; MT- million tonnes; m- meter; cm- centimeter; Fig.- figure; s- seconds; L- liter.

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## Introduction

India is the largest milk-producing nation, with an annual production of 230.6 MT (NDDB, 2024). Milk processing is an energy-intensive activity; the use of solar energy can partly replace conventional sources of energy (Jaglan et al. 2018; Sharma et al. 2019; Sain et al. 2020; Hosouli et al. 2023; Zlaoui et al. 2023; Patel and Patel, 2024). It was reported that if solar energy is used, about 30,000 L of milk gets pasteurized, and there will be a saving of 80–100 L of furnace oil on a daily basis (Kedare et al. 2012). Operations such as electricity generation, water heating/cooling, drying, steam generation, pumping of dairy fluids, and others can be performed using solar energy (Chopde et al. 2016; Sharma et al. 2017; Sain et al. 2020). In contrast, thermal energy storage (TES) materials are gaining much attention because they enhance energy efficiency, facilitate renewable energy Integration, and offer economic benefits (Rohit et al. 2023; Masera et al. 2023). The processing of milk and other perishable agricultural products may benefit from the use of TES materials in conjunction with solar energy (Sain et al. 2019a; Munir et al. 2023).

Research efforts should be made to find the aforementioned combination as well as develop equipment for such activities. This paper deals with the performance evaluation of a system developed for entrapping solar heat via a thermal storage fluid, transferring heat from the thermal storage fluid to water for heating, and using the generated hot water for milk processing. The aim of the study was to enhance the working hours, beyond the availability of daily sunshine hours, for milk processing when only solar energy is used as a thermal heat source.

## Materials and Methods

The study was performed at the Department of Dairy Engineering, College of Dairy Science and Technology, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, at 30.8929 latitude and 75.7981 longitude and an altitude of 245 m above mean sea level.

**Description of the heat reservoir**

A predesigned mild steel single cavity (Sharma et al. 2019) named configuration 1 (shown in Fig. 1a) was used for the selection of suitable TES material. Another mild steel two-cavity thermal reservoir named configuration 2 and configuration 3 (Figs. 1b and 1c, respectively) was developed in the study performed by Sain et al. (2019b). Referring to Figs. 1b, and 1c, Section 1 (oil side) had a volume of 6 L, and Section 2 (water side) had an 18 L volume. The scheme was to use the minimum amount of water in Section 2 so that it can be converted into steam using the least energy from the oil in Section 1; the rest of the energy stored in the oil should be available for temperature compensation in Section 3. This is due to the fact that there would be a temperature drop in the water present in Section 3 because it would be circulated for the heating of milk. So, the temperature drops of water need to be raised again to maintain the constant temperature of water for milk heating.

Basically, Configuration 3 was a modification of Configuration 2. In Configuration 2, the following method was used for hot water generation:

**Configuration 2:** A copper pipe of diameter 12 mm was coiled with a total length of 3 m; water passing through this coil gets heated up, taking energy from the steam in section 2 (referred to as C22 hereafter) (Fig. 1b).

After removing the copper pipe, the modified configuration was named Configuration 3, which is as follows:

**Configuration 3:** The copper pipe was removed from the cavity, and the cylindrical cavity of volume 9.5 L capacity, fully filled with water, was used for hot water generation via heat exchange between section 3 and steam of section 2 of configuration 3 (to be referred to as C23 hereafter) (Fig. 1c).

In configuration 2, the water circulation in the copper pipe was started when the temperature in the second cavity was above 100°C, i.e., steaming. The water was circulated using a centrifugal pump after recording the time taken to achieve the circulation temperature (90°C) in Section 3. Similarly, in C23, Section 3 was completely filled with water. Water present in section 3 received the heat from hot water present in section 2, which was simultaneously getting heat from section 1, which was the only medium for the transfer of heat from one layer or section to another. The heat source from where section 1 was getting heat and transferring it to the other sections was solar energy only, and the reservoir was placed on the focal point of the parabolic dish. The complete setup with the thermal reservoir mounted on the parabolic dish is shown in Fig. 2a (Sain et al. 2019b).

Temperature profiles in Section 1 and Section 2 of Configuration 2 After achieving the desired temperature in Section 3, the thermal reservoir was taken off from the focal point of the parabolic solar dish and kept in the laboratory under ambient conditions. The fall in temperature in various sections of the setup was recorded to observe the time period for which paraffin oil can supply heat to the water in Section 2 in order to maintain the temperature above 90°C.

**A tube-in-tube type arrangement for milk heating**

A tube-in-tube type arrangement for milk processing was developed to check the milk's heating by using the designed thermal reservoir. The vessel was made of stainless steel (SS-304) with a thickness of 1 mm. The length of the vessel was 59 cm, with an internal diameter of 3.81 cm and an outer diameter of 5.08 cm. The capacity of the milk side cavity was 500 ml, and the waterside cavity was 500 ml. The vessel was insulated with the help of cotton and aluminum foil to prevent losses. There were two nozzles for the inlet and outlet of hot water, as shown in Fig. 2b. The assumptions made for the development of the arrangement were:

1) Heat transfers under steady-state conditions, as the temperature of the outer wall of the milk holder is assumed to be constant.

2) Heat transfers by conduction as each ring of the cylinder is at the same temperature. The reason behind this assumption was that milk was held in a tube/pipe, so it was a batch process where the outer wall of the tube remained at a constant temperature. Also, looking into the diameter of the tube, the milk would be heated more radially than longitudinally. Thus, instead of convection, conduction was assumed.

3) Heat accumulation will occur as the milk side temperature rises from ambient to processing temperature.

4) There will be no heat losses to the environment as the water cavity is insulated.

**Methodology for heating milk using a tube-in-tube type heat exchanger**

A simulation study was conducted to assess the hot water temperature drop at 90°C and the milk temperature rise from 30°C. The drop in temperature was not compensated by heating. It was a batch process where milk was poured into the inner side cavity, and 9.5 L of hot water was circulated through the outer jacket with the help of a centrifugal pump. The heated water (around 90°C) was collected in an insulated container, as shown in Fig. 2b. A drop in the temperature of the circulating water and an increase in the temperature of the milk was noted with the help of a mercury thermometer.

Here, in this paper, the performance analysis of only configuration 2 (C22 and C23) is reported, as configuration 1 was used only for

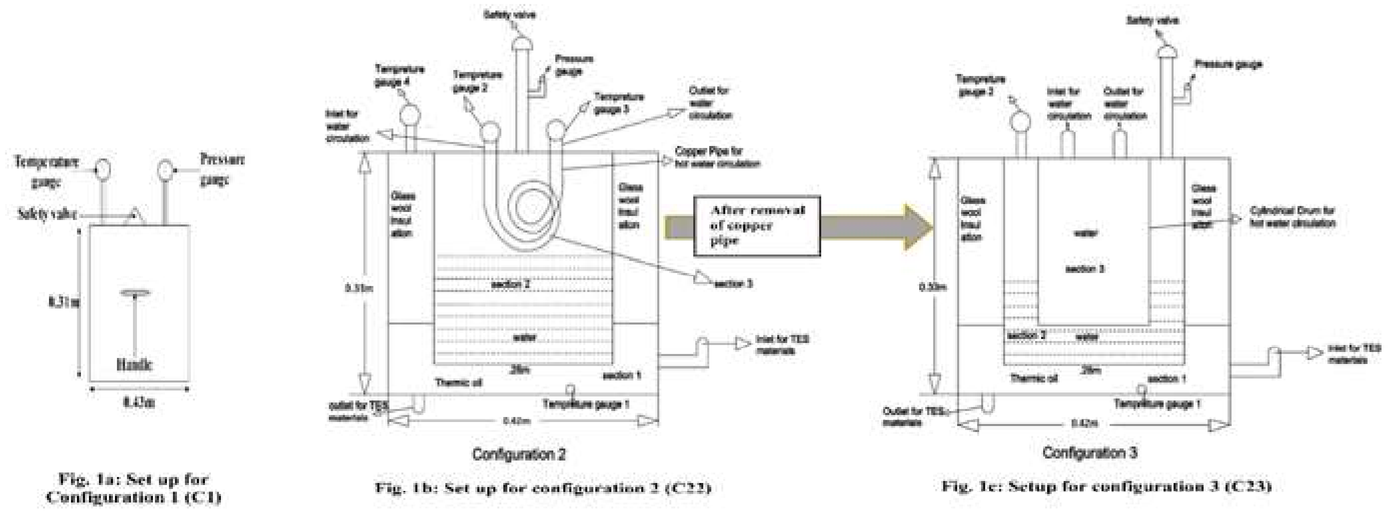


**Fig. 1** Schematic diagrams for all three configurations (Sain et al. 2019b)

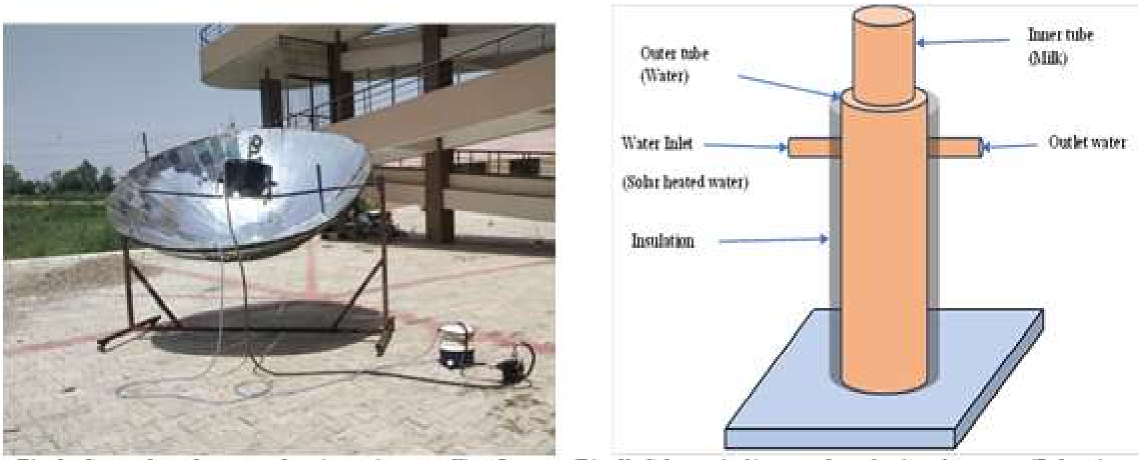


Fig. 2a Set up for solar water heating using paraffin oil   Fig. 2b Schematic diagram for tube-in-tube type milk heating equipment

**Fig. 2** Solar setup for water heating and schematic diagram for milk heating equipment

a preliminary study to ascertain the temperature attainment by the thermal fluid.

## Results and Discussion

### *Performance evaluation of the solar thermal reservoir*

### Configuration 2:C22

It was found that paraffin oil followed a logarithmic trend line, as shown in Fig. 3a, under various outside temperatures as compared to a straight-line trend under configuration 1 during the preliminary study (Sain et al. 2019a). It can be due to the simultaneous heat transfer from section 1 to section 2 (at the same time, section 1 was getting heated by the concentrated solar radiation as it was placed at the focal point of the concentrator, as shown in Fig. 2a) in comparison to the single cavity in configuration 1 (Sain et al. 2019a), where no simultaneous heat transfer occurred to any fluid.

When the temperature in section 2 exceeded 100°C, water circulation was started in section 3 through the copper pipe (Sain et al. 2019b). The temperature profile of water in Section 2 of C22 is shown in Fig. 3b. It shows that the water present in Section 2, which was receiving heat from paraffin oil (in Section 1), followed a linear trend line. The $R^2$ values under different weather conditions ranged from 0.68305 to 0.9266. Similarly, the $R^2$ values for paraffin oil ranged from 0.59759 to 0.90307 under various weather conditions during the study period.

From Fig. 3b, it can also be observed that the temperature of the water was raised to 90°C within 30 to 40 minutes, depending on the outside dry bulb temperature. The temperature differential was maintained between the paraffin oil and the water as the two curves became parallel to each other after attaining peak

**Fig. 3** Temperature profile curves in C22

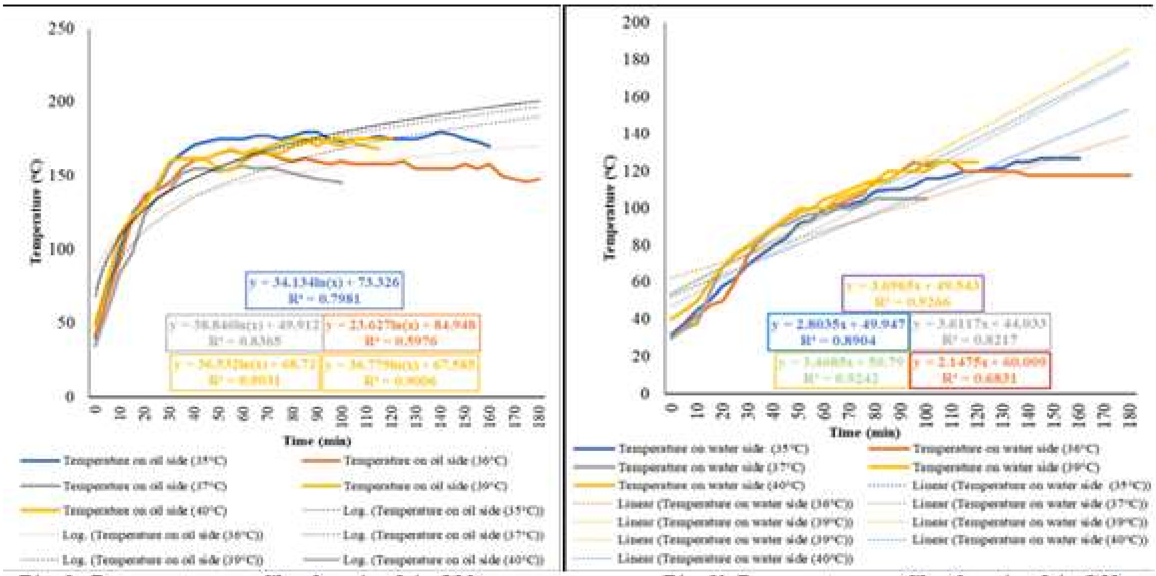


Fig. 3a Temperature profile of section 1 in C22 | Fig. 3b Temperature profile of section 2 in C22

**Fig. 4** Temperature profile curves in C23

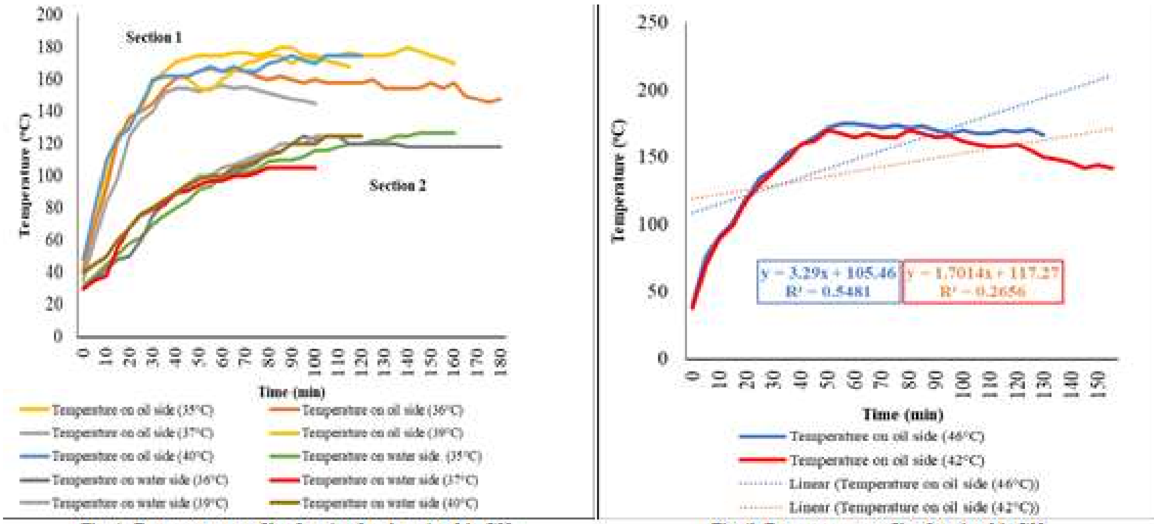


Fig. 4a Temperature profile of section 1 and section 2 in C22 | Fig. 4b Temperature profile of section 1 in C23

temperatures, as shown in Fig. 4a. The gradient varied from 20°C to 90°C under various weather conditions. It shows that paraffin oil holds enough energy to supply and maintain the water temperature in Section 2. The temperatures attained by paraffin oil during the study were 175, 170, 168, 148, and 145°C under different weather conditions, i.e., 40°C sunny, 35°C sunny, 39°C sunny, 36°C partly cloudy, and 37°C sunny with heavy wind, respectively. These mentioned temperatures were for the experiment period, which was on different days when plenty of sunshine was available to conduct the experiment.

**Configuration 2: C23**

When the temperature in Section 3 reached the desired temperature of 90°C, water circulation was started. It was observed that after 30 minutes of continuous circulation, there was a drop of 10°C of water in Section 3. The temperature profiles of Section 1 and Section 2 can be seen in Figs. 4b, 5a, and 5b.

**Time taken to attain the desired circulation temperature**

As shown in Fig. 6a, the time taken by water to achieve a temperature of 90°C in C22 was 220 minutes, whereas it was 115 minutes in the case of C23. There was a significant difference in the time taken to achieve the desired circulation temperature of 90°C in C23 compared to that in C22. This may be due to the fact that in C22, a small heat exchange surface area was available; less residence time inside the copper tube as the volume of the copper tube was very low (0.333 L). Whereas the surface area (0.231$m^2$) of the cylindrical drum (section 3) in contact with hot water and steam (section 2) in C23 was higher, so was the high residence time of water due to the larger volume of the cylindrical

**Fig. 5** Temperature profile of water and paraffin oil in C23

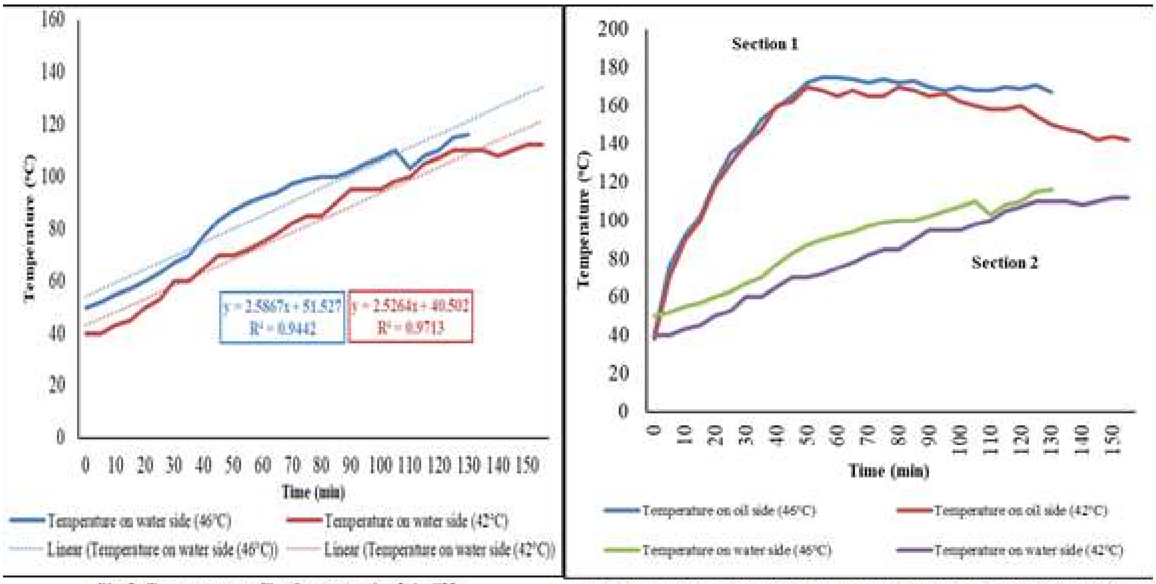


Fig. 5a Temperature profile of water (section 2) in C23

Fig. 5b Temperature profile of paraffin oil (section 1) and water (section 2) in C23

**Fig. 6** Temperature stability curves for paraffin oil and water

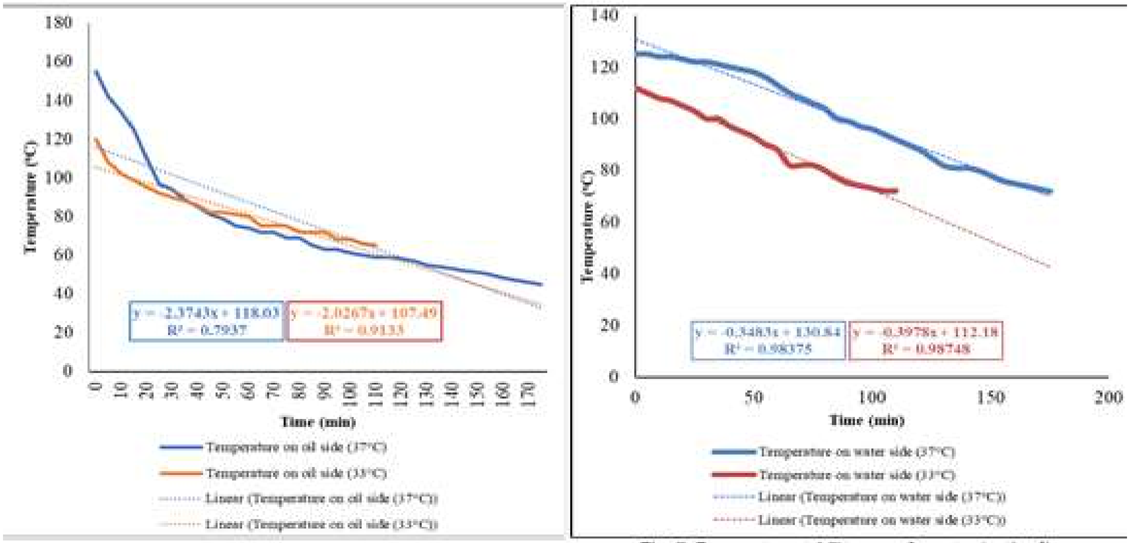


Fig. 6a Temperature stability curve for paraffin oil (section 1)

Fig. 6b Temperature stability curve for water (section 2)

drum (9.5 L), which gave better heat transfer. It may also be because, in C22, steam heated the water in a copper pipe, so the time water takes in Section 2 to get converted to steam contributes towards the longer duration of 220 minutes. Also, the copper pipe was not in contact with water in Section 2.

**Temperature stability of paraffin oil and water**

After the attainment of maximum temperatures by paraffin oil (section 1) and water (section 2), it was required to observe the stability of temperatures in both sections. A fall in temperature was recorded at an interval of 5 minutes to observe the temperature stability in both sections. The temperature stability of paraffin oil and water can be seen in Figs. 6a and 6b, respectively. The curve followed the linear trend with a negative slope. It was observed that the hot water temperature could be maintained for at least 1 to 2 h even when the setup was placed in the laboratory under ambient conditions. Preliminary trials of the present study and an earlier study by Sharma et al. (2019) found that the most effective time to process the milk using solar parabolic concentrator energy under available sunshine is about 4 h, whereas, with the use of thermal energy storage oil, the processing hours were increased to 5 to 6 h. So, the present study has shown the possibility of increasing processing time by at least 25 to 50 percent (4 h of efficient sunshine and an additional 1-2 h from the thermal energy stored by paraffin oil) depending upon the ambient conditions by using paraffin oil as a thermal energy storage material (Sain et al. 2019a).

**Table 1:** Performance evaluation of tube-in-tube milk processing equipment

| Time (seconds) | Temperature of) circulating water (90°C | Temperature of milk (°C) |
|---|---|---|
| 0 | 90 | 30 |
| 60 | 84 | 40 |
| 160 | 80 | 63 |
| 175 | 78 | 73 |
| 180 | 77 | 75 |

**Performance evaluation of developed tube-in-tube-type milk processing equipment**

Table 1 shows the fall in temperature of hot water from the initial temperature of 90°C and the rise in temperature of milk from the initial temperature of 30°C. It was recorded that the milk temperature rose from an initial 30 to 75°C, i.e., temperature above 72°C (milk pasteurization temperature), which is required for continuous pasteurization of milk. The temperature was attained in 180 s or 3 minutes. From the experiment, it was found that solar energy, in combination with paraffin oil as a thermal storage substance, can be effectively used to attain pasteurization temperatures for the continuous pasteurization of milk. It implies that milk can also be batch-pasteurized using the setup used in the present study.

**Conclusion**

The present study has revealed that a solar parabolic dish, along with a three-cavity container having paraffin oil as a TES material, can attain sufficient temperature to process milk even during off-peak sun hours. The sole aim of the study was to extend working hours using solar energy, which was successfully attained by increasing the available energy time by 25 to 50 percent. C23 was found to be better than C22 as it took less time (115 minutes) to achieve circulation temperature (90°C) as compared to C22 (220 minutes). The whole study was based on a lab scale setup, but a scaled-up, modified setup can be tested for its application in milk processing operations at a small-scale level. Also, the setup can be tested for plate heat exchangers, as they are widely used in the milk processing industries due to their high thermal efficiency.

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