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Application of Renewable Solar Energy for Thermal Treatment of Milk: A Review

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ABSTRACT

In India the milk is consumed both in the raw (un-processed) as well as processed forms with the raw milk being consumed locally. The use of processed milk is prevalent through both the organized as well as un-organized sectors. The milk processing in the organized sector (20% of the total milk processed) is undertaken to produce the pasteurized liquid milk as well as other value-added products. Solar energy is a cheap, omnipresent, and indigenous source of energy that produces a clean, pollution-free climate. In recent years, the use of solar energy has risen to new heights. Its driving force is the ongoing quest for an alternative power source due to the perceived shortage of fossil fuels. As the price of fossil fuels continues to increase, it has become much more common. The planet absorbs more energy from the sun in a single hour than the entire world consumes in a year. Its use has proved to be the most cost-effective, as most systems in individual applications only need a few kilowatts of electricity. Solar collectors transform solar energy into thermal energy for heating applications, which is the easiest and most effective way to do it. The dairy industry is one of the industries where thermal processing is a crucial unit activity. Solar energy can thus be used to heat water, sterilize cans and bottles, and pasteurize milk. This paper examines the use of solar energy in the pasteurization of milk.

KEYWORDS: Energy, fossils, milk, pasteurization, processing, renewable, solar, thermal

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1. INTRODUCTION

The growing population in India now increased the need for the dairy and food industries. But they usually use traditional energy sources. Nonetheless, as global warming rises, the government and different sectors are also searching for alternative sources such as wind, solar, and biomass (Afzal et al., 2017; Barba et al., 2019). Hard work was done to design and develop solar collectors for dairy. The use of solar energy is illustrated by the abundant accessibility of solar power in the country (Anumet al., 2017; Tasmin et al., 2022). Solar heaters can easily produce hot water, sterilize cans and bottles and pasteurize milk. Various kinds of solar water heaters have been developed and being used in dairies (Goddik and Sandra, 2002; Huang et al., 2018).

Milk is a necessary liquid for the nutrition and growth purpose of mankind. Milk is usually obtained from cow, buffalo and goat. The milk produced by the animals cannot be consumed by humanity directly. Therefore, first milk heating is required. Heating milk accurately kills bacteria and harmful microorganisms. The collection of energy from the sun may be a logical solution for solving the energy problem of scarce fuels. It is free and has no adverse environmental impact (Panchal et al., 2018; Beath et al., 2022). In different applications, the solar energy system as a non - conventional source is being created. It is primarily used in the process industries for heating cleaning and boiler feeding. This system is applied to the food industry, the milk industry, the textile, chemical and beverage industries for various purposes like water pumping, cleaning, sanitizing, drying, sterilization, distillation, cooling, cooling and air conditioning, because of its compact design and better heat transfer (Panchal and Shah, 2013). The way to heat a liquid below the boiling point to destroy microorganisms is called pasteurization. Louis Pasteur created it in 1864 to improve wine's storage qualities (Nkhonjera et al., 2017;Ganiyu et al., 2019). Panchal and Mohan (2017) proved that the use of partial or full solar energy reduce the cost compare to the conventional processing of milk.

Solar thermal systems provide solar radiation transition into heating, cooling or mechanical energy (Barba et al., 2019; Kumar et al., 2019). Solar radiation is first transformed into heat on surfaces exposed to this radiation in all thermal systems. Solar collectors are known as surfaces on which sunlight is absorbed and converted into heat in solar systems (Ayub et al., 2018; Schoeneberger et al., 2020). When heat transfer fluid such as air or water can flow over the collector, the absorbed heat can be removed. It will then move the heat to a designated place which might be a furnace, a cooling generator or a machine that transforms the heat into mechanical energy (Othman et al., 2016). The heat-carrying media's required temperatures depend on the application of the solar system (Kabir et al., 2018). Domestic heating requires 60° C. In a Rankine heat engine cycle, the heat transformation requires a minimum of 120° C (Powell et al., 2017). But in a turbo electric generator, superheated steam above 500° C is required (Panchal and Shah, 2013).

2. CONSTRUCTION AND WORKING OF SOLAR HEATING SYSTEM

A solar system usually has a collector, an enclosed or insulated tank, a pump, one or two heat exchangers and a control system. The collector absorbs the falling solar radiation and transfers it to the working medium (Abdelrazik et al., 2018). The heated working fluid such as water is either stored until needed for use in an enclosed tank or liquid can be directly heated. The pump moves the working fluid from where the working fluid gives the solar heat to the process by means of a heat recovery and heat exchanger(Al-Waeli et al., 2017). The control system is typically the thermostat or valve which controls the system operation. The following is explained about the processes of collection and storage, which are major operations of solar heaters (Hadiya and Katariya, 2013).

2.1. Collector

It has a dark surface consisting generally of metal, which absorbs sunlight and transfers it to the thermal fluid or working fluid(Mustayen et al., 2014). The collector is usually isolated by a thick insulation of 2.8–8.0 cm in order to avoid heat loss in the environment. The collector is protected by glass or plastic to allow for the absorption of short waves but opaque and longer infrared radiations from the absorber (Wu et al., 2017). The glass cover normally is about 4–5 cm thick and heat is trapped like a greenhouse effect between the glass cover and the absorber plate. The absorber plate is usually 0.2–0.7 mm thick, 1–1.5 cm thick, and the pitch 5–12 cm thick (Verma et al., 2020). The absorber material must be more thermal conductive, heavier and more corrosion resistant. Due to higher thermal conductivity (385 W mK^{-1}), copper is preferred. Different glazing, reflectivity and transparency collectors are available at various wave lengths, heat retention and life expectancy (Panchal and Patel, 2017).

2.1.1. Flat plate collector

The flat plate collector uses a 1.5–3.0 m^2 thermal absorber within a single container. Inside a waterproof insulated housing the assembly is sealed under the frame in order to prevent thermal loss to the roof. Insulating materials must be selected in order to withstand a temperature of 300°C to survive direct sunlight exposure without any thermal stress known as "stagnation" (Hadiya and Katariya, 2013). The flat plat collectors are of two types:

2.1.1.1. Liquid flat plate

The method of heat transfer in the flat plate filled with liquid is conductivity. In this thermal conductivity, the rate of heat transfer is an important factor. Nevertheless, the thermal conductivity of the flat plate filled air is not an important parameter. The corrosion collector of flat - plate liquids is more critical compared to the air form (Zou et al., 2019).

2.1.1.2. *Air filled flat plate*

Similar to the flat plate collector filled with liquid, but in that air, fluid works. These are further classified as follows:

2.1.1.2.1. Porous type

Air passes through the plate of the absorber. Cooled air flows from the top surface and passes through the porous absorber plate. Porosity gives a higher surface heat transfer and more residence time due to pores friction (Yılmaz et al., 2020). Therefore, heating time is reduced, but pressure drops are higher. Examples of pore forms are: split or extended sheet, transpierced honey comb, broken bottle and overlapped glass type.

2.1.1.2.2. Non-porous type

Air flows across the absorber plate. The heat exchange takes place only on the surface, so the rate of heat exchange is comparatively smaller but storage time is much longer in such units. They are also classified into Simple flat, Finned flat and V-corrugated flat plates.

2.1.2. Concentrating type

When high temperature is needed, it is mounted. This is achieved through the focus on the absorbing surface of high intensity solar radiation (Xu et al., 2017). It uses a reflector or refractor optical system. The mirror form is used in refracting Fresnel lens style. The radiation in the smaller area is distributed in such a way that radiation is magnified in the form of 1.5 or 2.0 to 10.000 times as a result, fluid passes can be heated to 500° C(Goddik and Sandra, 2002). These are of following types:

2.1.2.1. Focusing type

This optical system focuses on the absorber for solar radiation. Such collectors are line-focusing and point-focusing types which can be 150–400°C or higher than 500°C or greater (Wingert et al., 2020). In line focusing, solar radiation is centered on the thermal fluid stream, while solar radiation in the point-focusing form is focused on the small volume (point) through which thermal fluid flows.

2.1.2.2. Non-focusing type

The plate type is altered and the ray can be absorbed by means of reflection in the mirror. They are categorized as: flat plate collector and parabolic concentrator compound (Wang et al., 2016).

2.2. Transfer

For circulating fluid, the energy is transmitted into the storage tank with a natural or forced circulator. The pipe consists of copper, aluminum or steel. Copper is preferably utilized because of its high thermal conductivity (385 $W.m^{-1} K^{-1}$) which enables the faster transfer of heat from the absorber to the storage tank. The fluid used in the absorber pipelines is either water or aqueous glycol that can be used for the processing of the subzero temperature. Nielsen and Pederson (2001) gave the same concept. The heat transfer is carried out by heat-exchanger from the working fluid (recirculated in the collector) to the main fluid (storage tank) (Wayua et al., 2013)

2.3. Storage

Hot water is stored in a room or on the roof of the thermo-syphonic system until it is necessary later and the heated fluid in case of milk is cooled further. The principal cost of solar thermal systems is the collector field (54%), the storage tank and the heat exchanger (24%). It is a solar water heater that uses the sun 's thermal energy to heat water. They are generally intended to heat water to a sufficiently hot temperature for milk processing such as preheating (45°C) and pasteurization (72–15 s^{-1}) of milk (Schnitzer et al., 2007).

The collector consists of the number of rear-colored pipes that absorb heat energy and are added to the tank in order to store heated water. To prevent heat loss, the tank is insulated. Water is cycled several times through the collector to increase the temperature. The water can be passed via a thermos-syphonic effect (passive heating system) or by using an active heating system. The effect of thermos-siphon increases hot water above cold water due to the difference in density (Wayua et al., 2013).

Water circulates and gets warmer during sunshine, but the reverse occurs at night and heats the environment at about 0.3 m below the tank to avoid this edge of the collector. Recently, a number of chemicals or chemical mixtures, called phase change materials have served as storage materials rather than water. The melting points of these chemicals are within the desired temperature range (Hadiya and Katariya, 2013). Thus, they can store latent fusion heat, reducing storage space requirements and also allowing process operation within a narrow temperature range without falling significantly.

3. PASTEURIZATION PROCESS/ STUDIES BASED ON SOLAR ENERGY

3.1. Milk pasteurizing plant using solar energy

Lucentitni et al. (2001) have investigated the technical and economic feasibility of an innovative solar energy pasteurization facility and have tested it under different conditions throughout the year. They used a typical heat exchanger that offers various advantages such as safety, higher thermal and hydraulic performance and a lower surface height ratio. Typical pasteurizer thermal cycle is shown in Figure 1 depicting the milk input temperature, thermal temperature recovery, milk production rate and temperature pasteurization.

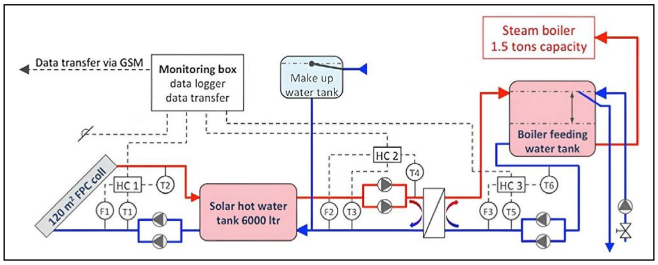

Figure 1: Solar milk pasteurizing plant (Source-Lucentitni et al., 2001)

3.2. Solar Panel-Based Milk Pasteurization System

Nielsen and Pedersen (2001) designed, developed and analyzed control systems used for solar pasteurization via solar panels. Pasteurization device analysis is based on different requirements of different power sources, low cost, low complexity and a simple user interface. The solar panel pasteurization system is shown in Figure 2. The demand was around 1000 liters daily with about 5 hours of sunshine, and pasteurization is therefore around 200 l h^{-1}. For the pasteurization process, solar cells were prepared to provide 12 V DC (Al-Waeli et al., 2017).

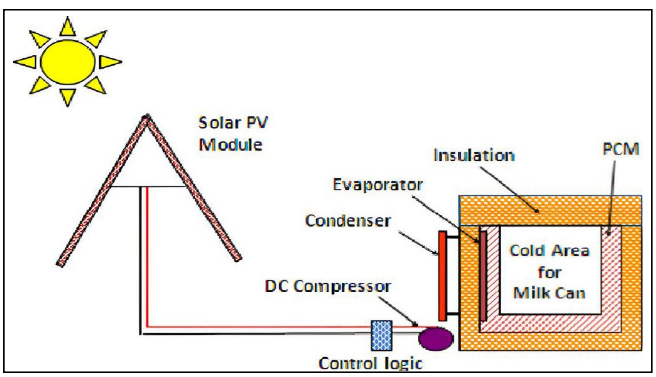

Figure 2: The solar panel pasteurization system (Source-Nielsen and Pedersen, 2001)

3.3. Pasteurization system by low-cost solar concentrator

Franco et al. (2008) developed low-cost (without sun tracking) solar concentrator for goat milk pasteurizing for the production of cheese. they used a solar concentrator Fresnel-type with a focal length of 55 cm and 6.6 kg for solar pasteurization and manufactured in the house and used the electric boiler to heat the water in the Pyrex breaker concentrate (Bader and Lipinski, 2017). They conducted a series of experiments for pasteurization with a specific amount of milk. After a series of tests, found that the low-cost concentrate type of Fresnel has pasteurized 101 L of milk for about 1 h, and it has energy retrieval time of about 8 years (Fletcher, 2001).

3.4. Solar Milk Pasteurizer with the Help of Flat-Plate Collector

Saad et al. (2021) designed and develop a solar milk pasteurizer in Suhar city in the Sultanate of Oman. The purpose was to design and develop a pasteurizer that is economically affordable and can be locally fabricated, later study the effect of tilt angle on the thermal performance of the pasteurizer. The design specifications were carefully selected and concept designs were introduced (Oosthuizen et al., 2020). The screening process is carried out to select the promising concept as a final design. The final design concept consists of a solar collector and milk pasteurization vat. The theoretical calculations performed and the results showed that the solar collector area of 1.5×1 m^2 is needed to reach milk temperature between (63°C–70°C) and hold it for 30 minutes. The tilted angle of 27 degrees gives better results compared with 24 degrees (Müller et al., 2020) (Fgure 3).

Figure 3: Solar pasteurization system with the aid of flat-plate collector (Saad et al., 2021)

3.5. Solar pasteurization system with the aid of evacuated tubes collector

Dobrowsky et al. (2015) have developed a solar pasteurization device for the production of large volumes of pasteurized milk by means of the evacuated tube collector. For research work they used aluminum, lead and nickel from the stainless-steel holding tank. After several tests, they found that the milk bacteria killed at 72 deg and above the temperature. They pasteurized approximately 500 l of milk. Figure 4 shows solar pasteurization system line diagram based on evacuated tubes (Figure 4).

Researcher compared the above pasteurization system layout

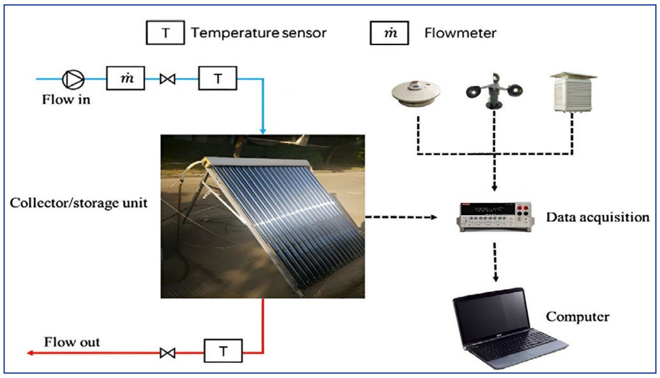

Figure 4: Solar pasteurization system based on evacuated tubes (Source- Dobrowsky et al., 2015)

with a new and improved solar-powered pasteurization system (Holler et al., 2021). They compared the energy repayment time between the existing plant and the updated plant base on the recommendations. Results found that the modified plant provides ₹ 7,20,000 month^{-1} and energy reimbursement time just approximately 3 months compared to the existing pasteurization plant. Haq et al. (2014) deliberate on the consequence of heat treatment on visual features and shelf-life of skimmed milk and found that the body/texture score and shelf-life are better with thermisation, pasteurization and sterilization processes.

Solar pasteurization using solar panels is a good solution, but energy repayment time is higher. The solar plant requires an energy recovery period of around 10–11 years, and when maintenance costs are included, they reach up to 20 years (Pregger et al., 2009). The sun milk pasteurizer attained pasteurization temperature in 1–1.5 h, so it can be used commercially for pasteurization. Sustainable solution is therefore required to overcome the energy payback increase. The 1.2 m^2 solar flat platform collector reached pasteurization temperatures in 3 to 19 m depending on the solar intensity available. The solar flat-plates pasteurization system produces an annual volume of 27,5 t, weighing 13.8 tons at around 63 and 72°C by average temperature (Barba et al., 2019).

4. ADVANTAGES AND DISADVANTAGES OF SOLAR HEATING

4.1. Advantages

Solar power is a clean and renewable source of energy. Once a solar panel is installed, free production of solar energy is possible. The energy will last forever and does not cause pollution, but the world's oil reserves are predicted to last for 30 to 40 years (Widyolar et al., 2021). Solar cells make no noise whatsoever, the giant devices used to pump oil are, on the other hand, extremely noisy and therefore very inexorable. Very little maintenance is required to keep solar cells in operation. There are no moving parts in a solar cell that prevents them from killing them properly (Ismail et al., 2021). In the long term, a high investment return can be achieved thanks to the amount of free energy produced by solar panels, it is estimated that 50% of the household's average energy will come from solar panels (Goddik and Sandra, 2002).

4.2. Disadvantages

There are some limitations with the solar systems like panels can be expensive to install, which means that energy savings will be able to match initial investments for many years (Eswara and Ramakrishnarao, 2013). The electricity generation completely depends on the exposure of a country to sunlight; this can be limited by the climate of a country. Solar power plants do not match the electricity output of conventional power plants of similar sizes; it may also be very costly to build (Herrando et al. 2021). Solar power is used for charging batteries, enabling the use of solar-powered devices at night. The batteries can often be large and heavy, take up space and have to be replaced occasionally(Kecebas, 2013).

5. CONCLUSION

The solar pasteurization system is essential for the killing of milk-based bacteria. A direct method was used for obtaining pasteurization temperature by use of solar energy for minimum and maximum fluid temperature of 63 and 78°C. A Fresnel low-cost solar concentrator obtained a pasteurization temperature of about 40 m instead of 1 h, but this depends on the temperature. Thus, the solar energy has an immense application in the thermal processing of the milk.

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