

Research Article

Implementation of Solar Heat Energy and Adsorption Cooling Mechanism for Milk Pasteurization Application

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The use of renewable energy is crucial to the global growth of sustainability. Milk business amongst many other food industry divisions requires a significant amount of energy, making the meal processing business one of the most energy-intensive industries. As of right now, more than 30 percent of the dairy produced in India is processed. In distant parts of India, milk spoiling is more common due to the delay among milking and storing; as a result, facilities for quick pasteurization and storage are needed. Heated is necessary for pasteurization. Since for a long time, the Indian milk industry has relied on nonrenewable energy sources, that are not only becoming much more costly but are also to blame for significant environmental issues including greenhouse gases and health issues. Consequently, scientific communities, environmental and social organizations, and the governments have all pushed the use of green energy. Solar energy has been shown to be the most viable among various sustainable and renewable energies given the geographical position of India. Solar energy can be used to pasteurize milk because of the energy intensity and range of temperature requirements. Adsorbent refrigerator is recommended here since it is powered by waste/solar heat and can store (200 liters of milk) at low temperatures until it is distributed after the pasteurization process (easily available from farm waste). The solar collector of evacuated tube is used for minimizing heat loss and pasteurizing milk. The outcome demonstrates that milk can be simply pasteurized at 73°C for 25 minutes at a flow rate of 5 liter per minutes. A solar energy adsorbent refrigeration system has been constructed and described for keeping 200 liters of milk at 10-15°C for 9-11 hours. Investigation findings indicate that the specific cooling power of the system is sufficient to store 200 liters of milk at 5.8 kW/kg and 5.5 kW/kg for 500 liter per hours hot water supplied at 92°C, 32°C condenser temperatures, and 5°C evaporator temperatures. The heat loss of evacuated tube collector is compared to solar concentrator. The study results provide evacuated tube collector is better for pasteurizing milk since to its highly efficient, longevity, and compactness.

1. Introduction

Every industry's and hence any nation's, economic progress depends on energy [1]. India is moving closer to being a developed country, and it has been noted that over the past 20 years, its energy usage has risen by around 6%. The requirement for easy accessibility of activities and commodities has made it difficult for business owners to meet customer demand. This holds true for all industrial sectors, such as the dairy sector. Presently, India produces 176.4 million tonnes of milk annually, or 7.8% of global milk output [2]. Due to the population boom, rising incomes, and more variety in milk products, it is anticipated that milk consumption would rise in the nearish term. The purchasing, marketing, and processing of dairy and milk products, as well as the representation of producers at the federal and state levels, are all major responsibilities of dairy cooperatives [3].

A healthy and balanced diet should include milk because of its highly nutritious qualities. Dairy is regarded as a complete food since it includes lactose and proteins in addition to all the other essential elements. Over than six billion people are consuming milk products and dairy globally. With an annual production of 187.7 MT and a daily supply of 394 grammes of milk per person, India is the world's leading producer [4]. Since Indian independence, small and marginal dairy farmers have generated 70% of the country's milk, and dairy has been a significant factor in the development of the regional economy and socioeconomic change. After the white revolution, India's milk supply rarely looked back, and it is now significantly contributes to the wellness of Indians. The recent analysis of FAO (Food and Agriculture Organization) statistics found that the globe produces approximately 804,887,098 tonnes of dairy annually. India is one of the world's emerging economies. In addition, it boasts the second-largest population in the world after China. Therefore, as the population grows, so does the demand for milk products. Additionally, India has roughly 5 lakhs of cattle from which milk may be obtained and subsequently given to the dairy facilities [5]. Hence, it is crucial for people's health to produce safer milk through the pasteurization procedure.

There are many renewable energy options including geothermal, solar, and wind. The energy collected from the sun is the most accessible and significant form of energy since it is renewable, nonpolluting, inexhaustible, and clean. Additionally, solar power contributes to pollution reduction and environmental stability [6, 7]. For various applications, the solar energy system has been developed as a nonconventional resource. It is often used for water purification and boiler feed in industrial operations. The system is used in dairy, food, textile, chemical agriculture, and beverage industries for various tasks including cleaning and sanitizing, water pumping, cooling, disinfection, filtration, drying, refrigeration, and air conditioning. Figure 1 depicts the solar usage in industrial applications. This is possible owing to the compactness layout of the equipment and high hotness.

India's increasing population has raised the demand for the food and dairy businesses. It did, however, typically rely on traditional energy sources. However, the governments

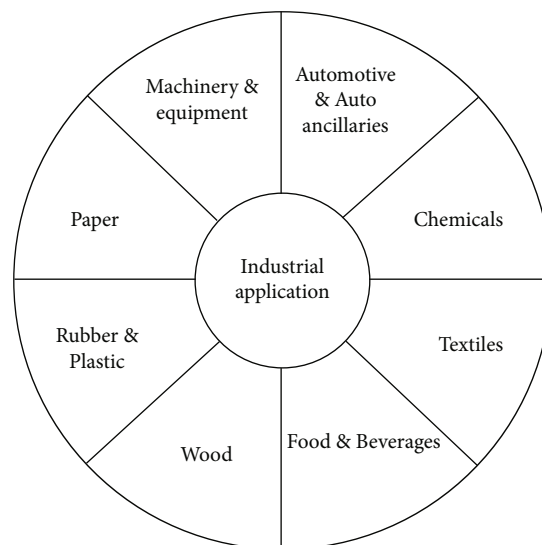


FIGURE 1: Solar usage in industrial.

and other industries are also looking for unconventional sources like wind, solar, and biomass owing to the acceleration of global warming. Solar collectors for dairy have been designed and developed with a lot of effort. Considering that solar energy is extensively available throughout the nation, its use is frequently promoted. The hot water required for cleaning, sterilizing bottles and cans, and pasteurizing milk can readily be produced by solar heaters. Various solar water heater designs were created and put to use in dairy [8]. Due to the need for thermal heating and cooling, the food industry, particularly the dairy industry, is highly sought after for solar energy applications. The dairy business uses 35 solar thermal systems, nine of which are located in European countries including France, Greece, Italy, and the Netherlands. The other three solar thermal systems use Fresnel reflectors and parabola through collectors to deliver steam at 140°C and 200°C and pressures between 4 and 12 bars. Three of the nine solar thermal systems use flat plate collectors to preheat and clean hot water to meet 20°C to 80°C ranges of temperature. Essential points of the solar power system that have already been employed in the pasteurized plant to reach operating temperatures ranging from 63°C to 72°C include solar collectors, heat exchangers, and water heating systems [9]. Figure 2 represents the various reasons for selecting the solar energy.

In France, the Louis Pasteur has established that heated wine at 55-65°C destroyed the spoilage organisms and assisted in its preserving; the word pasteurization was created. The use of this method gave rise to the word "pasteurization", that quickly gained popularity in technical jargon. Though Louis Pasteur was a pioneer in investigations on thermal treatment for preserving, several scientists may have contributed to the first sterilizing thermal treatment for dairy [10]. For different heat operations, the dairy business needs steam at a pressure of roughly 2 kg/cm². The major heat operation, pasteurization (0.3 kg/l of milk), is one of many. Utilizing solar heated water, whether complete or partial, will lower fuel costs [11]. In the dairy sector, heating

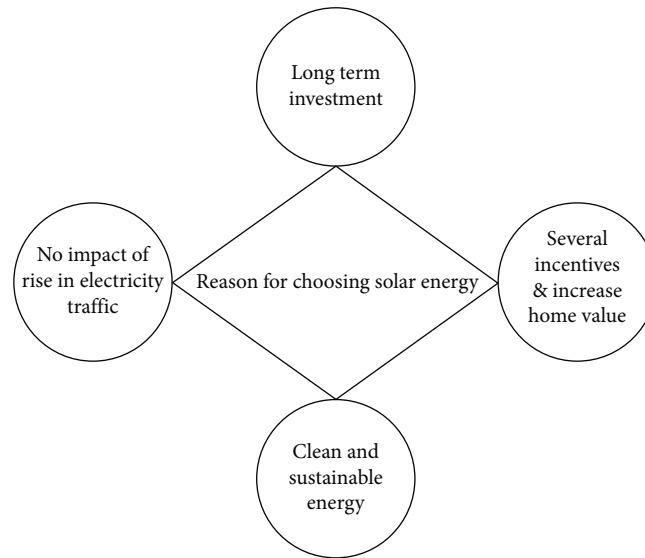


FIGURE 2: Various reason for selecting solar energy.

and cooling are frequent activities, and plates or tube heat transfer are typically utilized for these activities. One of the most well-known thermal treatments in a dairy processing center is pasteurization, that is carried out between 60 and 75°C depending on the process types [12]. The FSSAI defines “pasteurization” and “pasteurized” as the procedure of heating each substance of dairy of various sections to minimum 65°C and carrying at such temperature continued for at least 30 min or heating it to at least 72°C and carrying at certain temperature progressively for minimum 20 sec or another authorized time-temperature mixture that will give a negative test of phosphatase [13]. Solar pasteurization systems have been the focus of several international studies. Figure 3 depicts the pasteurization process in different temperature.

In the pasteurization process, hot water specifically provides the heat transfer, and the necessary energy is given by using various energy sources, including natural gas, coal, electricity, and renewable energy sources. In the modern world, growth in population and technology advances has both contributed to an increase in energy consumption. Moreover, since the Earth’s fossil fuel supplies have been depleting, the use of renewable energy sources (such as solar, wind, and geothermal power,) has become more crucial for a sustainable society [14]. Geothermal energy is one of the renewable sources that has a wide range of uses, including both industrial and domestic heating and cooling in addition to electricity generation [15]. Figure 4 represents the various benefits for pasteurization process.

Geothermal power may be regarded as one of the finest possibilities as a renewable energy source for milk operations because the pasteurization of milk requires both heating and cooling operations concurrently. Typical vapor absorption techniques, which have fewer initial and continuing expenses than cooling towers, are the most used option for cooling purposes. Moreover, the chlorofluorocarbon refrigerants utilized in typical systems are not eco-friendly. In addition to being environmentally benign, the water ammo-

nia absorption cycle that uses water ammonia combination as a refrigerant also delivers the refrigerated temperature required for a milk operation [16]. On the other side, it would be more cost-effective if the water ammonia absorption cycle was driven by heat energy among 100 and 200°C. Consequently, geothermal energy is considered as a source of heat for water ammonia VAC systems (vapor absorption cycle). An absorbent, evaporation, a desorbed, a condenser, a heat exchanger, expanding valves, and a pump make up the absorption cycle. This system circulates ammonia (an absorber) and water (a refrigerator) to produce chilling [17].

Solar dairy pasteurization is the method of eliminating microorganisms from dairy and eradicating germs from it using the sun radiation [18]. With the aid of a solar vacuum tube collecting, that generates hot water at an extremely high temperature, the sun’s beams are used to create steam [19]. Dairy is a naturally occurring liquids diet, and it is one of the most nutrient-dense diets. Whenever milk is handled poorly, the circumstances that the microorganisms create can spread. Antibiotic depositions in dairy brought on by the widespread use of antibiotics in animals used for food production are the alleged cause for both dairy production and consumer demand. A sufficient temperature and amount of time must be administered to kill the bacteria or microorganisms that grow slowly or produce holes [20]. Figure 5 depicts the various components for solar milk heater.

Since its operations need for more mild heat temperatures than those of other major industries, such as the chemical, textile, and paper industries, the dairy industry, along with other food industries, it has been singled out for its great potential for adopting solar technology [21]. The dairy must be chilled at 44°C or rising temperatures during farm production in order to meet the processing standards for dairy products, based on the national regulations of every nation. Based on product kind, the industrialized milk factories next perform various heat processes including

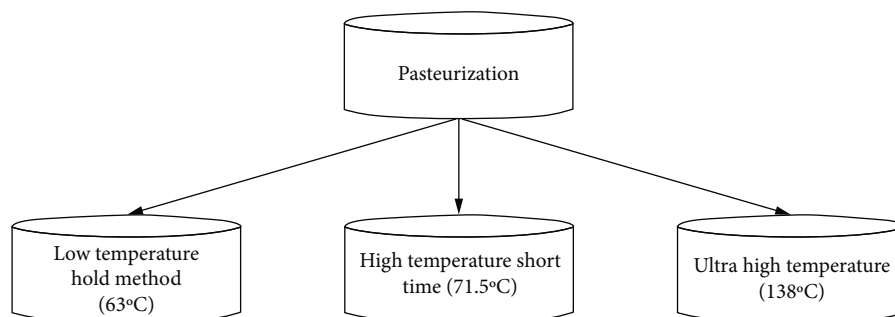


FIGURE 3: Pasteurization process in different temperature.

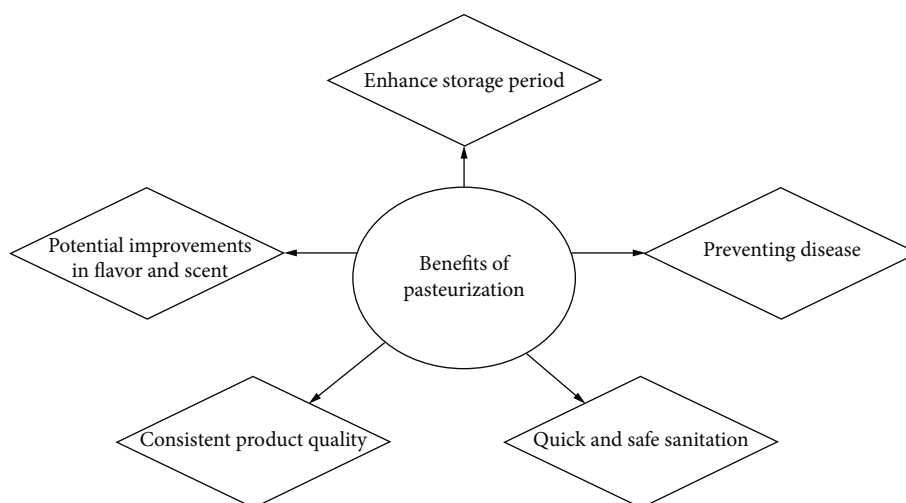


FIGURE 4: Various benefits for pasteurization.

pasteurization, sterilization, and ultrapasteurization. Presently, the worldwide dairy industry's output is made up of around 21% fluid milk usage [22]. Ultrapasteurization and pasteurization are the most used heat processes for fluid milk. This milk can be kept for five days after a standard pasteurization, but after receiving an ultrapasteurization process, it may be kept for three months. Whilst ultrapasteurization is the heat action that is most frequently used in established geographic regions, pasteurization is the thermal process that is regularly employed in emerging geographical area. Moreover, in industrialized regions, pasteurization is still employed to make a tiny amount of fluid milk with a short shelf life as well as other significant goods like cheese and yoghurt. The pasteurization of milk entails keeping the milk among 65 and 79°C for a predetermined amount of time, after which the milk must be quickly chilled to 4°C [23].

2. Related Works

One of the key dairy products, milk serves as a crucial component in the feed composition for infants and developing kids as well as adults. Moreover, the pasteurization framework's temperature has a significant impact on the final product performance. Hence, it is important to keep the ideal temperature throughout the pasteurization process

since excessive heat destroys all of the vital nutrients present in the finished product, and minimum temperature is undesirable because the product will not have the appropriate nutrient value. As an outcome, a crucial prerequisite for pasteurizing dairy is the implementation of an ideal temperature control strategy. In light of the foregoing, this study present the application of a proportion (P), integrated (I), and derivatives (D), or PID, control for optimum control of temperature during the pasteurization of dairy. The first law of thermodynamics was used to simulate the milk pasteurization temperature, and three distinct tuning approaches, Zigler-Nichols (ZN), Cohen-Coon (CC), and Chien-Hrones-Reswick (CHR), were used to fine-tune the PID controller for the best pasteurization temperature management. The effectiveness of every tuned strategy was assessed using the rising time, settling time, peak amplitude, and overshoot. The control systems were modeled in MATLAB/Simulink. The outcomes demonstrated that the ZN tuned PID controller provided the settling time, minimum rising time, and peak amplitude of 0.34 s, 0.177 s, and 0.993, accordingly. ZN and CHR both achieved the lowest overrun of 0%. According to these findings, the CC tuned PID controller had a mild rising time of 1.02 seconds, settling time of 6.49 seconds, and an overshoot of 5.67 percent, suggesting that its effectiveness was relatively better than that of the other tuned strategies examined. The findings

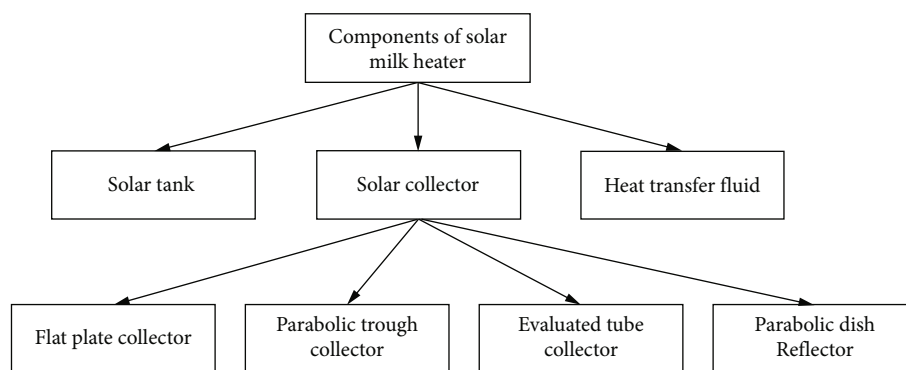


FIGURE 5: Components for solar milk heater.

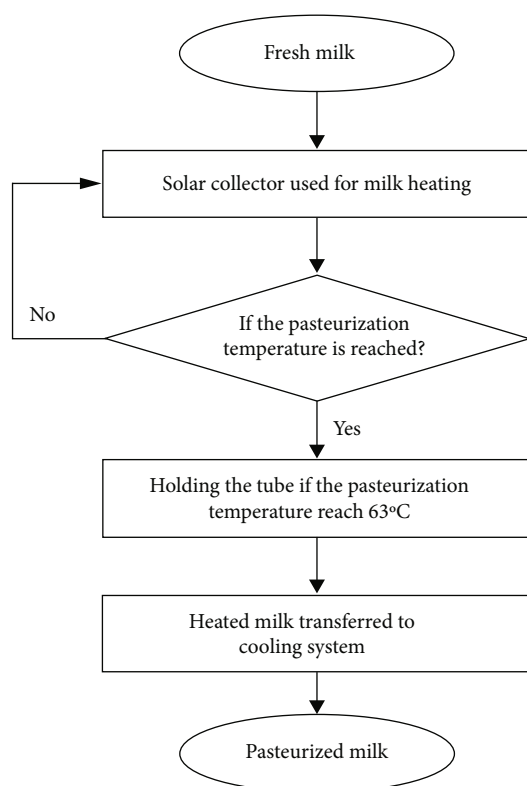


FIGURE 6: Process flow diagram for pasteurized milk.

of this study have applications in the dairy industry since they provide light on how to best tune a PID controller for optimal control of temperature during milk pasteurization. This approach is not suitable because it causes steady-state error [24].

Given the right environment, *Staphylococcus aureus* can produce staphylococcal enterotoxin A (SEA), an essential biotoxin that frequently contaminates dairy and milk items. Herein, SEA protein was injected into BALB; the immune chromatographic assay (ICA) is generated and developed the anti-SEA monoclonal antibody utilizing extremely fluorescent quantum dot beads (QB) as a signal amplification assay for rapid and accurate detection of SEA in pasteurized milk. The suggested QB-ICA demonstrates superior SEA sensitivity identification in real milk specimens with a detec-

tion range of 2 ng/mL and shows excellent dynamic linearity for SEA quantifiable identification from 3 to 160 ng/mL within 20 minutes of testing time, provided the 1030-fold improvements in the photoluminescence intensity of QB to the original quantum dot. With a low cross-reaction to typical analogues, such as E, D, C, and B, staphylococcal enterotoxins are suggested QB-ICA also exhibits strong selectivity to SEA identification. Additionally, by examining specimens of milk that had been enriched with SEA, the precision and accuracy of QB-ICA were evaluated. The coefficients of variation vary from 4.6 to 14.2 percent and the median recovery of intra- and interassays ranging from 85.5 to 128.1 percent, demonstrating a tolerable precision for the quantifiable determination of SEA in actual milk specimens. In conclusion, the work offers a potent and quick analytical technique for the proper supervision of SEA contamination in specimens of pasteurizing milk. For SEA quantified identification in actual milk samples, the suggested QB-ICA also shown acceptable specificity and acceptable accuracy. In pasteurized milk and other food ingredient, this investigation demonstrated a significant possibility for the on-site sensitivity identification of SEA contamination [25].

Dairy and milk products may be vulnerable to risks like aflatoxin M1 (AFM1). Aflatoxin generation has an impact by a quantity of variables, containing changes in the environment and an absence of sufficient substrates for feed healthier livestock. The study seeks to lower the toxicity level in pasteurizing milk to a value under that recommended by the European Codex Alimentarius Commission. In order to achieve this, the appropriate construction of the radioactive granite stone was first created as a minimum level gamma irradiation without interaction with pasteurizing milk. This milk comprising AFM1 that is positioned in this framework is evaluated, and the results comparing to the values of the control specimens utilizing AOAC technique. The LLGI dosing rates and the subsequent decrease in aflatoxin in the milk are then determined. With the use of the Monte Carlo N-Particle Transportation Protocol, the LLGI dosage rate is computed (MCNP). For modeling, the mass of every composition of pasteurizing milk and its constituent components is also estimated in addition to the spectra of gamma irradiation released by radioactivity granites. In comparison to the control specimen, the findings demonstrated a 51.5 percent drop in aflatoxin in pasteurizing milk

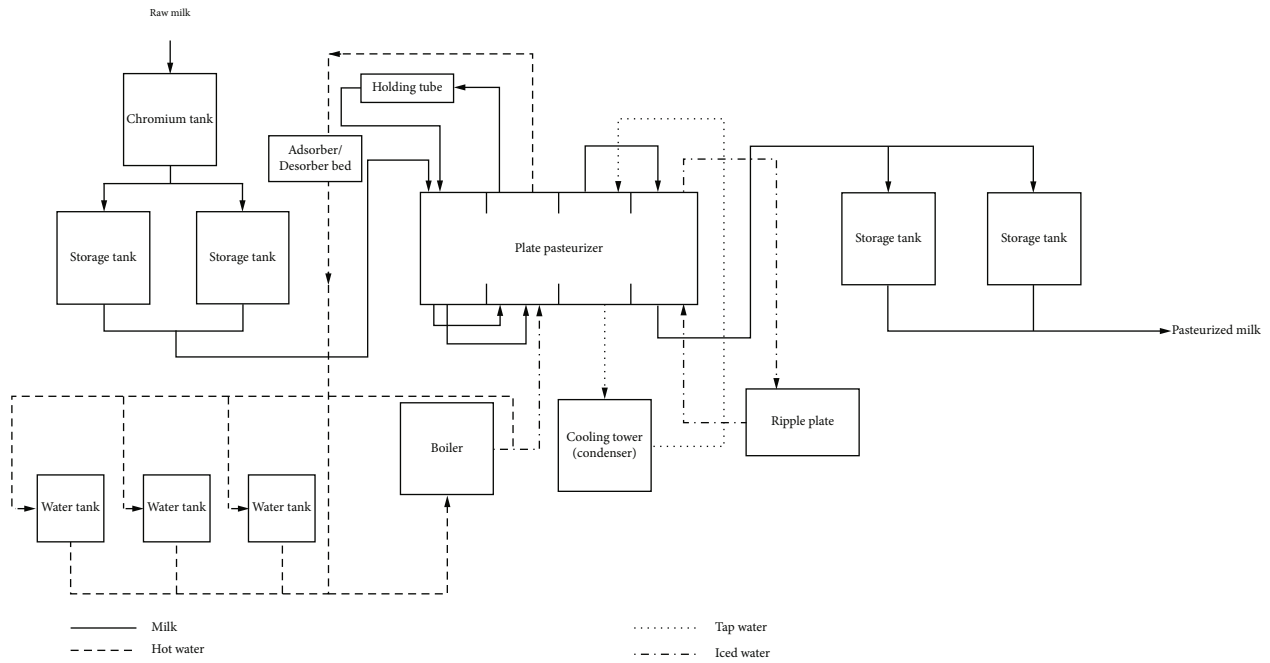


FIGURE 7: Schematic representation of pasteurized milk process.

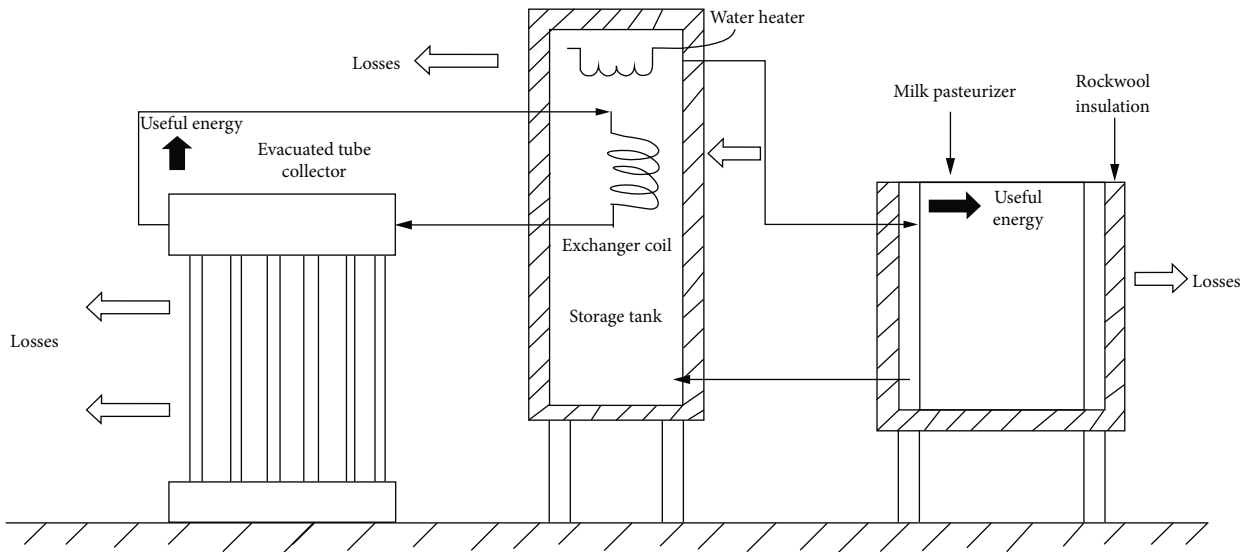


FIGURE 8: Milk pasteurization working process by using evacuated tube collector.

after 5 days, and a 99 percent reduction after 8 days. In dairy, the LLGI dosage level is 0.40 mGy per day. A global atomic energy agency research and prior findings indicate that this dosage rates level can increase milk's shelf life and improve safety without adversely affecting its chemical or sensory qualities. As a result, one of the acceptable strategies for lowering aflatoxin may be regarded to be the building built utilizing radioactive granite in this investigation [26].

Determining the heating process of milk is crucial since it is the greatest popular method for ensuring the microbial safety of dairy. Additionally, a rising issue in the dairy industry is the adulteration or mislabeling of pricey milk specimens like goat or sheep milk with cow's milk. Therefore, it is vital for both consumers and producers that milk speci-

mens' validity be determined. The study's objective was to distinguish between raw and pasteurized milk specimens utilizing partial least squared discriminant analysis (PLS-DA) and Raman spectroscopy first in terms of whether the dairy had been heated or not and then in terms of species (cow, goat, ewe, and mixed (adulterated)). Firstly, PLS-DA was utilized to distinguish between raw and pasteurized milk specimens. High specificity and sensitivity ratings were attained for pasteurized and raw milk samples in both calibrating and estimation techniques. Secondly, the suggested technique distinguished between pasteurized and raw milk specimens based on their species (cow, goat, sheep, and mixed). The specificity and sensitivity ratios were above 0.857 and 0.897 in the calibrating and forecasting

approaches, accordingly. Additionally, the precision scores exceeded 0.915. The findings demonstrate that the specimens were classified in a good and accurate manner. The findings indicate that milk samples may be effectively differentiated as per thermal treatment and species within 20 seconds per specimen using Raman spectroscopy in conjunction with PLS-DA. It was discovered that Raman spectra offer useful data that may be utilized, in particular, to distinguish between milk samples based on their origination [27].

The activated enzyme alkaline phosphatase (ALP) can be found in raw dairy. It is used as an indication to assess the effectiveness of the pasteurization process because to its distinctive heat-sensitive features. In the current work, a technique for measuring the activity of the ALP enzymes in pasteurized milk was devised using HPLC and a fluorescent detection. The process is focused on the identification and measurement of 4-methylumbelliferone (4MU), which is released when the dairy enzyme phosphatase reacts with the substrate 4-methylumbelliferyl phosphate (4MUP). Clarity, centrifuge, and solid phase extraction procedures were used to obtain and purify 4MU. With the use of a reversed-phase C18 column and gradients eluted made up of a binaries mobile phase comprising of HPLC grade methanol and water, the targeted component isolation was accomplished. The excitation and emission wavelengths of 365 and 460 nm, accordingly, were used to identify fluorescent. High specificity, strong linearity ($r_2 > 0.9901$), minimal limits of identification (LOD, 0.349 mg/L), minimal limits of quantifying (LOQ, 0.432 mg/L), accuracy ($> 100\%$), and accuracy (percent RSD 4.7652) were all demonstrated clearly in the technique evaluation studies. When compared to the Lovibond comparability approach, it was discovered that the HPLC method had the benefit of being able to identify contaminating of raw milk and ALP activation at extremely low levels. It is the first account of using an HPLC-fluorescence detection approach to find ALP at such low levels in dairy. The present standard techniques that use fluorometric technology for determining ALP activities in pasteurized milk might be regarded to be replaced by this novel chromatography approach. The quality assurance criteria now used in the dairy sector could benefit from this approach [28].

The ultrapasteurization and high-temperature short-time pasteurization (HTST) are two methods for pasteurizing fluid milk (UP). Although investigations have not conclusively shown it, the literature claims that UP enhances dairy astringency. Therefore, the goal of this research was to ascertain how milk's sensory and mechanical characteristics were affected by the pasteurization process, fat level, homogenized pressure, and storage period. Raw skim (0.3% fat), 3 percent, and 6 percent fat milk was homogenized at 20.7 MPa, pasteurizing in triplicate by indirect UP (150°C, 2.5 s) or by HTST (78°C, 16 s), and then kept at 4°C for 8 weeks. In addition, indirect UP was used to processing 2 percent fat milk, which was then homogenized at pressures of 13.8, 20.7, and 27.6 MPa and kept at 4°C for eight weeks. The milk was assessed for sensory profiled, instrumental viscosity, and frictional profiling at 25°C after

1, 4, and 8 weeks of storage. Protein structural changes in dairy at these times were examined using confocal laser scanning microscopy and sodium dodecyl sulphate polyacrylamide gel electrophoresis (PAGE). For eight week assessments, fresh HTST milk was analyzed at 7 weeks. Comparing to HTST pasteurization, ultrapasteurization enhanced the sensory and instrumental viscosity of milk. The fat content increased astringency and frictional profiles while decreasing sensory and instrumental viscosity. For UP vs. HTST, astringency, combined regimens frictional profiles, and perceived viscosity all enhanced. Increasing the storage period has no impact on the mechanical or sensory viscosity. Moreover, longer storing times typically led to higher astringency and frictional characteristics. When comparing to HTST milk, UP milk had more denatured whey protein, according to results from confocal laser scanning microscopy and sodium dodecyl sulphate PAGE. The rise in viscosity and frictional levels during storage was probably brought on by the aggregation or network these protein and casein micelles produced. The mechanical viscosity, astringency, or frictional behaviors were not substantially affected by the homogeneity force; moreover, specimens homogenized at 14 MPa as opposed to 21 and 28 MPa had greater sensory viscosity. In HTST milk and UP milk, astringency and frictional coefficients at 100 m/s slide speed were positively connected, while sensory viscosity and mechanical viscosity at a shearing rate of 50 s⁻¹ were strongly correlated ($r_2 = 0.90$). Experimental assessment can therefore be utilized to identify specific milk sensory characteristics [29].

3. Methodology

3.1. Pasteurization of Milk Utilizing Solar Energy and Evacuated Tubes. There are many other ways to combine different solar gatherers type, but the ETC was selected for pasteurizing milk since to its highly efficient, longevity, and compactness. It also does not require a monitoring system. Glass vacuum tubes with concentric twin tube geometry were made of chromium. The 0.8 W/m² °C was the typical heat losing coefficients from tubes. Chromium steel tanks with a 200-liter storage capability were placed for the purpose of storing hot water. Up to 100+ °C may be attained with an evacuated tube solar collector. The following equations can be used to determine the evacuated tube collector area.

$$\text{Area}(a) = \left(\frac{WS_{hc}\nabla n}{T_i\tau\beta t\mu_{th}} \right), \quad (1)$$

where "W" stands for the weight of water (kg), "a" stands for the region of the absorber tube revealed to irradiation, " ∇n " stands for the temperature change of the milk in the pasteurizer, " S_{hc} " stands for the particular warmth capability of the milk to be pasteurizing, " β " stands for evacuated tube collector inner absorber tubes absorption coefficient, " τ " stands for transmission coefficient of evacuated tube collector outer glass tubes, " η_{th} " is the efficiency of thermal for the entire solar milk pasteurizing scheme, and "t" is the time in second stands. This covers all heat-energy-transfer losses from the

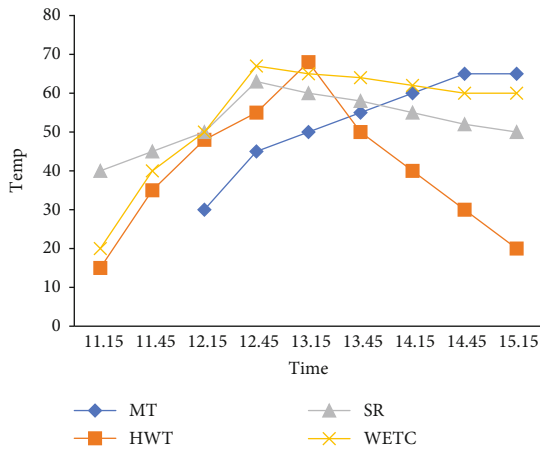


FIGURE 9: Performance evaluation of milk pasteurization by ETC (MT-milk temperature; HWT-hot water temperature; SR-solar radiation; WETC-water from ETC temperature).

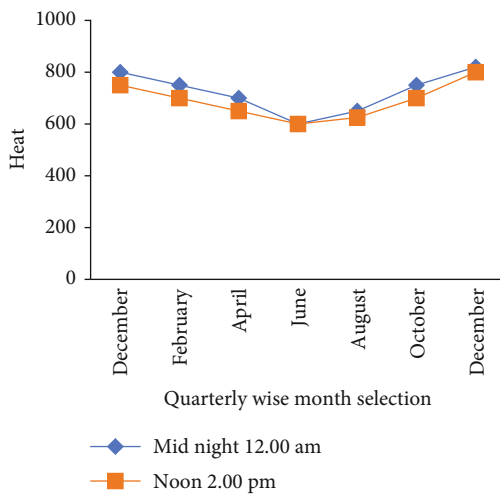


FIGURE 10: Solar irradiation absorption by ETC.

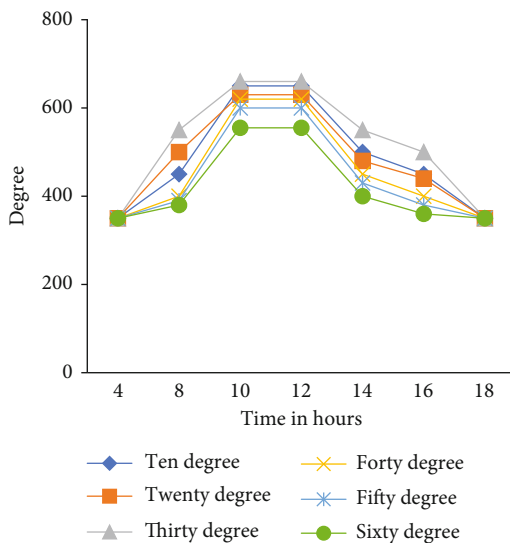


FIGURE 11: Absorption variance of solar radiation in various angles.

evacuated tube collector, milk pasteurizer, storage tank, and all associated pipe lines.

3.2. Design and Construction. Figure 6 depicts the process flow for a solar-powered milk pasteurizing technology. The unpasteurized milk storage tank is a cabinetry box shape chromium steel, with internal diameter of 2.20 m length, 2.20 m wide, and 0.90 m tall. This can hold around 200 L of milk daily basis. This can therefore encompass a limited milk-producing region. The provided milk is expected to be pasteurized among midnight twelve o'clock to two o'clock in the afternoon. The length of cylindrical parabolic concentrators for a continual flow process and focal length was identifying to be approximately 100 cm and 350 cm, correspondingly. An evacuated glass pipe has been installed near the sun's source of heat. The glass tube has a black coated to increase its ability to absorb solar infrared rays. The chromium tubes that run the whole height of the evacuation glass tube are within. The chromium tubes are 7 mm in diameter and 2.0 m in length. Whenever sunlight strikes the parabolic, it is reflecting off the surfaces and incidental light strikes the focal point where the glass tube is installed. The glass tube heats up as a result of this. Among the glass tube and the chromium tubing, there is a void.

The warming trend comes into effect, retaining the temperature inside the glass tube and causing the chromium tubes to heat up. This chromium tubes are heated to the necessary temperature as dairy is carried through them. The parabolic concentration is exposed to solar radiation. Estimated are the angles at which the rays strike the parabolic. Aluminum composite chromium evacuated tube was used to create the parabolic that was then welded to the framing component. The requisite heating of 73°C is reached at the parabola's output. It is then delivered to the cooling system from that. Thus, activated charcoal and methanol serve as the adsorbent operating pairings in an adsorbent cooler. The dairy is initially chilled to a minimum temperature of 5–6°C in the cooling unit. It is then transported to the last saving container, where it is kept refrigerated and in a controlled environment. A range of 15 and 20°C has been established as the storage condition. It is then delivered to the packaging facility where it is packaged before being delivered to the numerous places.

Figure 7 shows a diagrammatic representation of pasteurized milk process. The absorption chiller is heated by solar energy. Solar collectors are used for solar heating of flat surfaces. The functional counterparts of an absorption chiller are methanol and activated carbon, and the main components are an evaporator, desorber/adsorber, expansion valve, and condenser. The water jacket surrounds the adsorber/desorber bed and condenser, through which hot and cold water periodically flows through the mold. Porosity, the pores of activated charcoal, is occupied by methanol during decomposition. The temperature and pressure of the desorber bed is raised by hot water heated by the sun and circulated through it. With the help of a square pipe in the form of a spiral, the storage tank hot water is dispersed around the outside of the pasteurizer for efficient heat transfer to the milk filled inside. Moreover, in accordance with

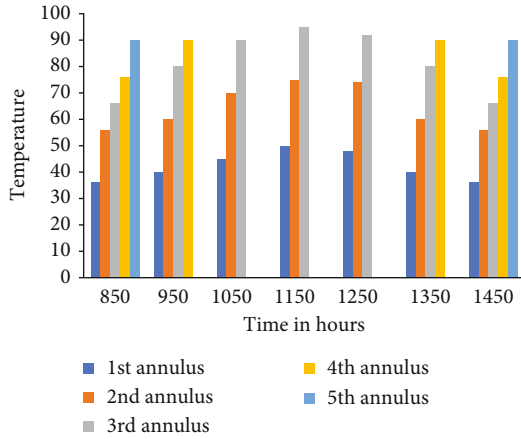


FIGURE 12: Need for evacuated tube collector in March 2021.

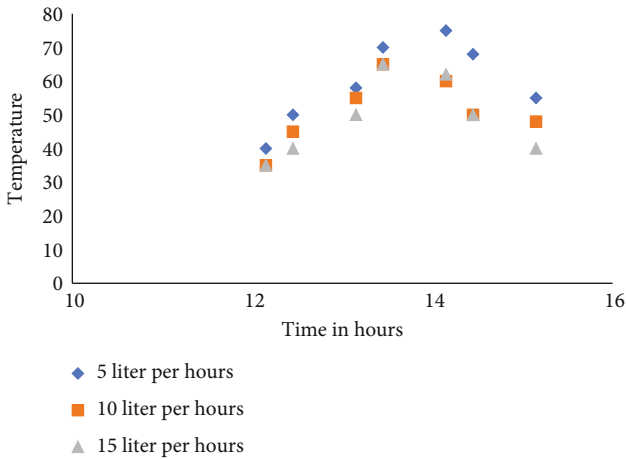


FIGURE 13: Various flow rates computation of milk temperature variation.

milk pasteurization regulations, the tank's materials are food-grade SS-304. Polyurethane insulates the pasteurizer's outside casing. For efficient pasteurization, the mechanical stirrer with a 58 rpm speed is fitted to disperse warmth evenly. Continually, lowering the milk's temperature, when the cooling procedure is carried out, is also beneficial. Within a GHI range of 600–800 W m², it is simple to get temperatures exceeding 100°C.

The valves between the desorber and condenser are opened after the desorber bed reaches condensation pressure. The expelled methanol then goes to condensation. Methanol releases heat in the condenser during the condensation process, and the condensed methanol goes to the expansion device. The heat of the milk is then stored in receivers before moving to the evaporator, where it is cooled by methanol. The pressure and temperature of the desorber bed are reduced by the circulation of cold water. The valves between the evaporator and desorber are released, and the desorption process begins, when the pressure in the desorber bed drops below the desorber pressure.

3.3. Energy Used and Lost in Milk Pasteurizer. Equation (2) shows the usable value of warmth energy obtainable at the

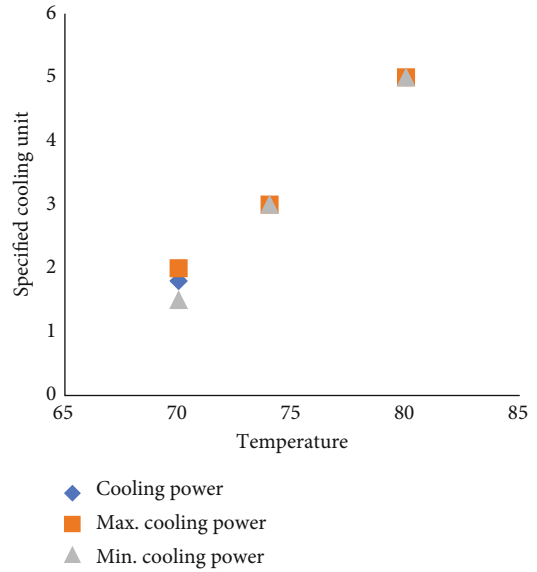


FIGURE 14: Various temperature cooling power uncertainty analysis.

tank of pasteurizer for pasteurizing milk.

$$E_p = E_r - E_{pt}, \quad (2)$$

where E_r stands for thermal and optical loss, and E_{pt} stands for thermal losses of receivers, convection, conduction, and radiation losses account for these losses. It is the tubular part of the pasteurizer is shielded with 45 mm rock wool insulating. By entering input data (bounding heat settings, material properties, shape, and features) into the algorithm created for milk pasteurizer, a full procedure was developed, and the outcome of thermal losses is determined. A 45 mm polyurethane insulating materials (the conductivity of thermal energy: 0.030W m⁻¹k⁻¹) was used to protect the bottom and side edges of the milk pasteurizer (432 × 559 mm). The inherent heat of vaporization of water was utilized to rapidly pasteurize milk at 65°C using wet steam from a steam receiver.

3.4. Calculation of Thermodynamic Losses of Steaming Receiver and Milk Pasteurizer. Ambient temperature and space temperature were taken as t_a and t_i , respectively, for all calculations. A cylindrical layer exposed to fluid convection on each side has the constant heat transfer which has denoted in Equation (3).

$$\varphi = \left(\frac{t_i - t_a}{r_{cd} + r_{cn}} \right). \quad (3)$$

While r_{cn} stands for convection resistance, and r_{cd} stands for conduction resistance, t_a is the ambient heat, and t_i is the temperature at the inner surface of the milk pasteurizer. In contrast, the following Equation (4) may be used to compute the heat conduction resistant from the

TABLE 1: Material properties utilized for evacuated tube collector.

Material	Characteristic	Rate
Wood	Heat conductance	0.15 W/m-K
	Density	16 mm
Aluminum	Heat conductance	190 W/m-K
	Thickness	4 mm
Air	Heat conductance	0.032 W/m-K
Polystyrene	Heat conductance	0.030 W/m-K
	Thickness	20 mm

TABLE 2: Processing attributes of investigational study.

Operational stipulation	Rate
Normal water inlet temperature	23°C–24°C
Flow rate mass of cold H ₂ O	300 LPH
Boiling H ₂ O inlet heat	85°C
Flow rate mass of hot H ₂ O	500 LPH
Condensation temperature	35°C
Initial bed temperature	30°C–40°C
Maximum bed temperature	70°C–80°C

cylindrical section of the pasteurizer.

$$r_{\text{cn}} = \frac{\ln(R_e/R_i)}{2 \times 3.14 \times \lambda \times l}. \quad (4)$$

While l denotes the pasteurizer or receiver's lateral length, λ denotes the material's thermal conductivity, R_i denotes the pasteurizer or receiver's interior radius, and R_e denotes the pasteurizer's exterior radius. The following Equation (5) can be used to determine the conductivity resistant of the pasteurizer or receiver's round portion.

$$r_{\text{cn}} = \left(\frac{T}{a\lambda} \right), \quad (5)$$

where " a " denotes the cross-sectional region of the round unit of the bottom of the pasteurizer or steam receiver, and T is the wall thickest of the round unit of the receiver or pasteurizer. With this insulating, it is possible to compute the conductivity resistant for additional layers, planar walls, and cylindrical segment by summing the conducting resistant of all layers and generalizing as following Equation (6).

$$r_{\text{cn}} = \sum_{\text{cn}}^i r. \quad (6)$$

While i depicts the layer of chromium steel, insulating material also covers tubes with various thicknesses and thermal conductivities. Equation (7) may be used to compute

convective resistant.

$$r_{\text{cn}} = \left(\frac{1}{H_f s} \right). \quad (7)$$

Equation (8) may be used to determine thermal losses through irradiation.

$$R_{\text{loss}} = s\delta\xi(t_e - t_s). \quad (8)$$

While emissivity is denoted as ξ , the Stephen Boltzmann constant is denoted as δ , the space temperature is denoted as t_s , and t_e stands for exterior area temperature; it can be computed by using the following Equation (9).

$$t_e = t_a + \varphi r_{\text{cn}}. \quad (9)$$

Compute the overall heat losses through radiations by changing the value of t_e in Equation (8). The overall losses of the system may be estimated by aggregating all the losses.

3.5. Losses and Energy Availability Utilizing Evacuated Tube Collector. The following Equation (10) provides the energy input for an evacuated tube collector.

$$E_v = \left(\frac{S_t A_s}{1000} \right), \quad (10)$$

where A_s is the evacuated tube collector surface region, and S_t is derived by multiplying the effectively tube length (exposing to solar radiation) by the diameter (aperture) and quantity of tubes, and E_v is the rate of incident solar energy at collector (kW).

The heat performance of a solar evacuated tube collector can range from 70% to 80% depending on solar energy input, loss, and temperature transmitted to the working fluid. The primary goal of the research is to conduct a heat assessment of solar milk pasteurization. The water and glycol solution receives heat from the exhaust pipe collector header and is then utilized to warm the outer shell of the cylindrical pasteurizer in the hot water storage tank. Therefore, multiplying the flow rate mass by the fluid's heat and variation in temperature, it is possible to determine the quantity of heat energy (Q) transmitted to the functioning fluid before being transmitted to the dairy. A further advantage of this method is the thermal energy storing in the hot water tank that may be utilized to effectively pasteurize milk even when there is little sunlight.

The following equation may be used to determine how much energy is needed to heat 200 liters of storage tank water from room temperature (30°C) to nearly 95°C.

$$H_w = NS_{\text{hc}} \nabla t, \quad (11)$$

where N is the water mass, ∇t is its specific warmth capability, and H is the value at which warmth energy must be delivered to the water. Equivalent calculations may be used to determine how much energy is needed to heat 90 L of milk to a change in temperature of 40°C. Then the valuable

energy obtainable for milk pasteurized tank “H” and the overall useful energy obtained from ETC “H” are computed to be 5460 W and 4070 W, accordingly. It is projected that the 18.8 m length of piping and fitting linking these 3 parts will result in total heat loss of 638 W. The pasteurizer and hot water tank both had estimated thermal losses of 116 and 90 W, accordingly. Figure 8 represents the milk pasteurization working process by using evacuated tube collector. Figure 9 depicts the performance evaluation of milk pasteurization by ETC.

4. Results and Discussion

Determining the median solar radiation (W-hr/m²) on an evacuated tube and the solar collector is crucial for sizing a solar adsorption process. There are certain days all year round with relatively little sun radiation. With clouds and wind, solar radiations vary. Therefore, it is crucial to understand solar radiation variations while designing heat storage systems of solar. The heating process for pasteurizing milk takes place from 11:00 am to 2:00 pm. Figure 10 depicts the typical solar radiation that evacuated tube collector in Pune, Maharashtra, India, which is located at geographic coordinates 18.5204 south and 73.8567 west, absorbs each month between 12:00 am and 2:00 pm. Despite the clear skies, the most solar radiation is attained in November and February (778 W hr/m²). Due to the wet period, irradiation is at its minimum in July and August (611 W hr/m²). On April 21, 2021, from 7 am to 4 pm, Figure 11 depicts the fluctuation in solar irradiance at the inclination angle (10°-50°). It demonstrates that in Figure 12, the 25° inclination angle produces the greatest results.

Solar heat is used as the system’s input power for adsorbent refrigerated. The reflectance of the glass tube is taken into account as 0.2 while designing solar evacuated tube collector. The sun insolation that falls on the evacuated tube solar collectible surfaces is absorbed. Owing to sun insolation, the water temperature flowing inside the evacuated tube collectors rises. However, there are heat losses (the differences in temperature among the inside and the surrounding air) from the top, bottom, and side sections. In comparison to the side and bottom sections, loss of heat from the top via the glass cover is every time greater. Irradiation and convection from the adsorbent tube to ambient are both taken into account when evaluating heat loss from the top.

For boiling fresh milk between midnight twelve o’clock and noon two o’clock, a tubular parabolic focusing gatherer has been created. The temperature of milk during heating is depicted in Figure 13 for various flow rates. The high liquid temperature for 5 LPH is 73°C at 2:00 PM. In Figure 14, it can be seen how the system’s highest temperature (T₃) changes the system’s particular cooling capacity. T₃ was varied at various temperatures (70°C, 73°C, and 76°C), with no changes to the other variables listed in Table 1. Ordinary water is utilized to make chilled water. Table 2 provides information about the investigation’s operational conditions. The change in specific cooling power (SCP) scores for three different deso-

ber bed temperatures is shown in Figure 14. The highest SCP value for desorber bed temperature at 80°C ranges from 52 to 57 kW/kg. SCP values can vary by ± 4.15 percent for uncertainty analysis. The volume of desorbed methanol grows together with the heat of the desorber bed, increasing the SCP of the adsorbent refrigeration.

The planned work is anticipated to provide the following advantages. The pasteurization will be performed right after milking, which will slow the growth of psychotropic bacteria. So, milk may be kept for a longer period of time. The milk may be kept by villagers for a very long period. The refrigerating scheme will be powered by biomass or solar heat to provide the heat needed for pasteurization and adsorbent. This will eliminate the need for energy, reduce operating costs, and reduce maintenance costs. CO₂ production will decrease since there will be less spoiling. The factory will be environmentally beneficial since the pasteurizing procedure and storing will be powered by non-conventional resources.

Under real-world circumstances, the thermal energy needed to pasteurizing 200 liters of milk at a temperature differential of 70 to 78 degrees Celsius was measured to be 5.8 kWh and 5.5 kWh, accordingly. Solar concentrated and evacuated tube collector efficiency was determined to be 90.25 percent and 95.25 percent, accordingly, as expected. Solar concentration and evacuated tube collector efficiency values under field settings were discovered to be 90 and 95 percent, accordingly. The effectiveness of an evacuated tube collector is much better than that of a solar concentrator in both circumstances (theoretical and real). Because comparing to a solar concentrator, evacuated tube collectors have far lower thermal and optical losses. Additionally, optical losses were used to compute the losses of thermal energy per unit of time. Both systems can be used efficiently for pasteurizing milk, according to the study’s findings, but the evacuated tube collector dependent solar milk pasteurizing method has proven to be more effective, inexpensive, steady, cost-effective, and compacted. It also offers better opportunities for milk processing decentralized.

4.1. Milk Pasteurizing in the Field with ETC. The temperatures of milk, water, glycol-water combination, and the sun’s irradiation are all shown in Figure 9. The figure clearly shows that the solution of glycol temperature climbed quickly and reached its highest value of 95°C within the constant range of sun light, maintaining virtually at this heat throughout the investigation. Additionally, it is clear from Figure 9 that the storage tank hot water gradually warms up to a maximum temperature of 80°C. The net primary energy was calculated to be 6 kWh to attain the pasteurizing temperature in 85 minutes. The pasteurized process median GHI was observed to be 800 W/m²; the median primary power on opening area (5.25 m²) of the evacuated tube collector was reported to be 4.5 kW. This test required 2.615 kW of power, using 3.91 kWh of energy overall over 1.5 hours. Under the current configuration of the milk pasteurization system operating on ETC, the effectiveness of the entire system was found to be 71.41 percent. Other trials produced similar findings.

5. Conclusions

In this research, the construction and effectiveness of a small milk storage system (200 liters capability) were examined. The pipes and containers are constructed of SS316. Solar thermal heating is employed for heating because it is readily accessible in India's rural areas, where power is scarce. An array of parabolic sun collectors has been used for heating. The outcome demonstrates that around 2:00 pm, the parabolic collectors produce the greatest outcomes. Milk can be held at a temperature of 73°C for 30 minutes while flowing at a rate of 5 LPH during that time. Thereafter, it is kept at 5 to 6°C in a chromium steel container for 30 minutes. Pasteurized milk is lastly kept in a finishing storage facility with regulated atmospheric conditions at a temperature between 15 and 20°C. Around 15 and 20°C has been chosen as the storage temperature. It is suggested to use an adsorbent refrigeration system for the cooling unit. Adsorbent cooling relies heavily on the choice of adsorbent pair. Activated carbon and methanol have been chosen and justified here after evaluating many academic works. Solar evacuated tube collectors are meant to power the adsorbent refrigeration unit. It is determined that 6 to 8 m² in size collectors are needed. Findings suggest that at a 25°C inclination angle, solar radiation collected by collectors was at its peak. Effectiveness of refrigeration systems had been estimated in terms of particular cooling energy. The highest specific cooling power value for desorber temperature at 78°C ranges from 50 to 60 kW/kg. Greater refrigerant is desorbed when the hot water temperature rises, raising the SCP as a result and raising the temperature of the bed. Both systems a solar concentrator and an evacuated tube collector may be used successfully for pasteurizing milk, but the system with the evacuated tube collector is more efficient, easier to build, and offers thermal storage so that the process can proceed in a variety of weather conditions. In the upcoming, this system may be powered by biogas that is readily accessible in rural regions from agricultural wastes.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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