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Design considerations for developing geothermal-assisted milk pasteurization equipment

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Abstract

The naturally occurring heat inside the earth is renewable and sustainable and is known as geothermal energy. It is a renewable energy source that may be used in various applications, including milk pasteurization. This research focuses on the design considerations for developing geothermal-assisted milk pasteurization equipment which is first of its kind in Gujarat, India in direct application of geothermal energy. The novelty of this device is that it utilizes geothermal water (63 °C) from a self-flowing well to pasteurise milk. The utilization of direct heat energy from geothermal resource reduces the operational cost of milk pasteurization process. It discusses the various aspects of the design process, including efficiency calculation, heat exchange principles, system components, and control strategies. The study also discusses the result of the laboratory analysis of pasteurized milk considering microbiological and chemical parameters. The unit reduces the total plate count to 28,000 cfu/ml, within the recommended range for the WHO (30,000 cfu/ml). The paper concludes by discussing societal benefits and techno economic aspect of geothermal-assisted milk pasteurization equipment.

Keywords Geothermal, Pasteurization, Heat exchanger, Heat utilization, Microbiological analysis

Introduction

The over utilization of non-renewable resources is exhausting the globe's reserves of fossil fuels which is a cause for concern and as such, an alternative is necessary (Alrikabi, 2014). Switching to renewable resources is one of the finest alternatives. Given the current situation, we can anticipate future job prospects in India's green energy sectors (Pachar, 2020). The need is to develop technologies to efficiently exploit renewable energy supplies (Dincer, 2000). Our green energy sector is centred on six renewable resources namely solar, wind, geothermal, tidal, hydro and biomass energy. Researchers have worked in respective fields to utilize renewable resources in different sectors. The need is to integrate all renewable energy in every sector, so that no part of our country is left behind in sustainable development. Among these geothermal energy is at a nascent stage in India (Shah et al., 2015) and work for setting up plants to utilize this resource is still in progress.

Accordingly, this study aims to provide an outline of geothermal energy and developing a unit for its utilization.

Geothermal as energy source

Geothermal energy is the energy which is existing inside the earth's core. India has excellent development potential and is home to a large number of hot springs and geysers, which are classified into seven geothermal provinces Himalayan (Puga, Chhumathang), Sahara Valley, Cambay Basin, Son-Narmada-Tapi (SONATA) lineament belt,

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West Coast, Godavari basin and Mahanadi basin (Singh et al., 2016). It has been identified as a potential source of sustainable energy. According to growth projections, geothermal energy will contribute 3% of electricity generation and 5% of heat load by 2050, removing more than 1 billion tonnes of carbon dioxide (Bertani, 2009; Edenhofer et al., 2011). It is been utilized for space heating and cooling, food drying, coffee, copra, and coconut drying, palm sugar processing, honey extraction, aquaculture, and more recently pasteurizing milk (Anugrah et al., 2021; Dhale et al., 2016; Kiruja, 2012; Yadav & Sircar, 2019). The demand for safe, affordable, and sustainable food processing technologies is increasing due to the rising global population and the need to reduce our dependence on fossil fuels (Ang et al., 2022). Thus, the global challenge is to avoid future energy shortages to meet agricultural and food demand due to the progressive increase in population (Chandrasekharam et al., 2019; Law et al., 2013; Vega et al., 2022). Establishing geothermal assisted Milk pasteurization will be moving one step towards utilization of geothermal energy in food sector.

Background

Since the emergence of the pasteurisation technology in the late nineteenth century by French scientist Louis Pasteur, it has become a standard practice in the dairy industry (Watts, 2016). Tables 2 and 3 represents the properties which are generally used for quality check of the milk. Milk Pasteurization is conventional technique to prevent milk spoilage, so that it can be transported to different locations. Proper time–temperature combination is necessary for the effective heating of the particles (Dhale et al., 2016). This increases the shelf life as well as ensures proper nutritional content. Studies have been conducted to test the efficiency of Heat treatment categories discussed in Table 1. Sterilization is a conventional method which requires in-container heating at 115–120 °C for 20–30 min (Gedam et al. 2007) while modern techniques incurs the use of equipment's to attain temperature. According to the study by John Samelis et al., Thermisation treatments eliminate dangerous bacteria but may have a detrimental influence on milk quality by lowering favourable Lactic acid bacteria (LAB) (Samelis et al., 2009). In North America High Temperature Short Time (HTST) pasteurization (72 °C for 16 s) was carried on human donor milk to check if it's more effective in reducing burden on milk as compared to their standard method of Holder Pasteurization and results for same were found to be in favour of HTST (Terpstra et al., 2007). While if we move towards Ultra High Temperature type (UHT), it requires minimum temperature of about 135 °C with holding time from 12 to 8 s. In India, the pilot plant for UHT type was first set up in 1970. Though UHT is very efficient, and reduces time and labour but it's quite expensive and requires more specific equipment (Gedam et al. 2007). Several researchers contradict and prefer Low temperature long time (LTLT) or Holder Pasteurization which requires holding for 30 min at 63 °C because involvement of higher temperature gives rise to a reduction in the overall bactericidal capacity of milk (Gedam et al. 2007).

The Indian milk industry has long been dependent on non-renewable energy sources, which are not only getting more expensive but are also responsible for serious environmental problems (Ramkumar et al., 2022). Thus, utilization renewable resources come into play.

Table 1 Main Heat treatment categories (Bylund, 1995)

Process	Thermisation	LTLT pasteurization	HTST pasteurization	Ultra pasteurization	UHT (flow Sterilisation) normally	Sterilisation in-container
Temperature (℃)	63–65	63	72–75	125–138	135–140	115–120
Time (Seconds)	15	1800	15–20	2–4	1–3	1200–1800

Table 2 Results of Microbiological Test

Characteristic test	Before pasteurization (Raw milk)	After pasteurization (Pasteurized milk)	WHO standard
Total plate count (cfu/ml)	69,000	28,000	30,000
Coliform count (cfu/ml)	< 1	< 1	100
E.coli (cfu/ml)	Absent	Absent	100
Yeast & Mould count (cfu/ml)	< 1	< 1	20

Table 3 Results of Chemical Test

Characteristic test	Before pasteurization (Raw milk)	After pasteurization (Pasteurized)	WHO standard
pH	6.5	6.72	6.7–6.9
Turbidity	0.9	0.85	< 1 NTU
Cadmium (mg/kg)	Absent	Absent	Max 1.5
Mercury (mg/kg)	Absent	Absent	Max 1.0
Lead (mg/kg)	Absent	Absent	Max 2.5
Arsenic (mg/kg)	Absent	Absent	Max 0.1
Fenproparthin (mg/kg)	Absent	Absent	0.1
Fenvalerate (mg/kg)	Absent	Absent	0.1
Acephate(mg/kg)	Absent	Absent	0.02
2,4- Dichlorophenoxy acetic acid (mg/kg)	Absent	Absent	0.05

The first dairy, processing milk using geothermal energy was reported in 1930 in Iceland while similar setups have been setup in 1976 and 1981 (Lund, 1997; Thorhallsson, 1988). Researchers in Indonesia have worked in the field and developed a unit that utilizes the heat energy of geothermal water to heat secondary water and further uses it for milk pasteurization (Anugrah et al., 2021) but India still lacks this technology.

Geothermal assisted milk pasteurization setup

The milk Pasteurization process is important for making milk safe for human consumption by inactivating pathogenic bacteria (Kiruja, 2012). Raw milk can be contaminated in several ways and thus this process involves heating milk to a temperature that kills disease-causing microorganisms and substantially reduces the levels of spoilage organisms (Watts, 2016). This process is typically done using conventional methods, such as steam or hot water baths. Geothermal-assisted milk pasteurization is an alternative method that uses the natural heat of geothermal sources to heat the milk. This method has the potential to reduce energy costs, improve overall efficiency, and reduce environmental impact (Kulasekara & Seynulabdeen, 2019). In addition, geothermal-assisted pasteurization can be implemented in small-scale operations, making it a more suitable option for rural areas where access to conventional energy sources may be limited.

This study provides an overview for developing Geothermal-assisted Milk Pasteurization Unit in India and assessment of milk quality to ensure the successful and sustainable working of the unit under available geothermal site conditions.

Design and operation criteria of a geothermal-assisted milk pasteurization unit

To successfully develop and implement a geothermal-assisted milk pasteurization system, several design considerations must be taken into account. These include:

- The type and size of the geothermal source,
- The type of heat exchanger used,
- The optimal temperature and
- Duration of the pasteurization process for the system.

Figure 1 depicts the Unai village in Navsari district of Gujarat which is the testing site for the geothermal-assisted pasteurisation unit. It lies between latitude 20° 84′86″N and longitude 73° 33′62″E (Pandey et al., 2023).

Unai is blessed with good potential sources of geothermal energy in the region. The geothermal zones in the region were identified based on two stage studies. The first stage is known as the prefeasibility stage where the preliminary study was done using remote sensing, geological prospecting, and geochemical prospecting of the region and the second stage involves a major part of the

Fig. 1 The milk pasteurization unit is designed for the study area depicted in the map

geophysical exploration. Based on the results obtained from these studies a geothermal well of approximately 1000ft is drilled with water temperature of 63 °C. The well is a self- flowing well with no extra energy required to pump out the water from well.

Based on the available conditions in Unai geothermal field the design and construction of the Geothermal-Assisted milk Pasteurization Equipment were carefully planned and executed. The unit is HTST type, i.e. it takes 15 s at 72 °C to heat the milk. It utilises plate heat exchangers for cooling process (Mitkari & Ronge, 2019). The equipment is user-friendly and easy to maintain and repair, with an intuitive user interface, easy-to-operate controls, food grade material (SS grade 304) and features that facilitate maintenance and repair. While milk is pasteurized using geothermal water the unit runs on Organic Rankine Cycle (ORC) set up in Unai for power production making it a sustainable unit. The economic feasibility of the system must also be considered, as geothermal systems typically require a higher initial investment than conventional methods.

Components of milk pasteurization unit

The unit is designed based on the temperature of available geothermal water at our site location. It is HTST type depending on the available temperature of geothermal water.

(i) Storage tanks and heating components

It comprises three tanks for retaining milk during and post-pasteurization, while an extra tank stores water from a secondary source in case of unavailability of live geothermal water during lab demonstrations. The milk tank is equipped with an additional insulation jacket for flowing water through it. For measuring the flow rate, an electromagnetic flow meter is set up.

(ii) Vapour compression refrigeration (VCR) components

They act by bringing down the temperature of milk up to 4 °C and receiving the final product. The design employs a fin and coil type condenser to increase the surface area which balances the thermal conductance on the sides of the minimum-size heat exchanger and balances pressure/ heat transfer contrast between fluid streams while Plate type heat exchanger is employed for the exchange of heat between milk and R407C fluid.

(iii) Miscellaneous

The rest of the unit comprises valves which can be operated as per requirement and pump switches, sensors, and drains which are common for all type of milk pasteurization unit.

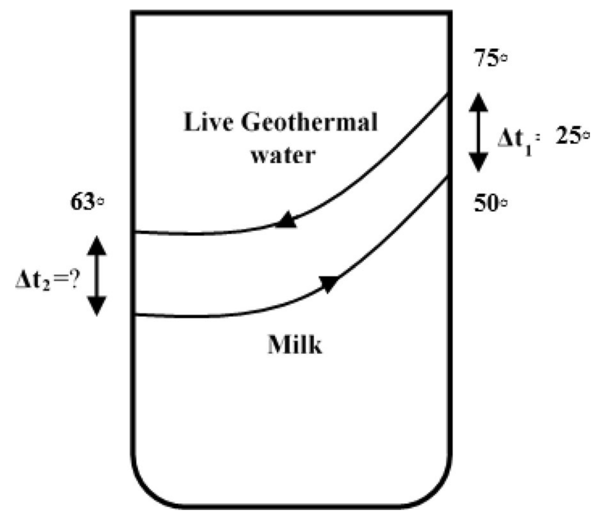

Fig. 2 Live geothermal water flow in heating tank

Mathematical modelling

Figure 2 represents the data utilized for the geothermal assisted milk pasteurization unit as per which the Inlet milk temperature = 50 °C, Outlet milk temperature = 75 °C, Inlet water temperature = 63 °C.

Live geothermal water temperature difference can be calculated using Eq. (1),

$$V_1 \times \rho_1 \times C_{p1} \times \Delta T_1 = V_2 \times \rho_2 \times C_{p2} \times \Delta T_2 \quad (1)$$

where, V_1 = Flow rate of milk (m^3/h), ρ_1 = Density of milk (kg/m^3), C_{p1} = Specific Heat of milk (kJ/kg. °C), ΔT_1 = Temperature change of milk (°C), V_2 = Flow rate of Water (m^3/h), ρ_2 = Density of Water (kg/m^3), C_{p2} = Specific Heat of Water (kJ/kg. °C), ΔT_2 = Temperature change of Water (°C).

For this system, the value of above mentioned parameter are,

$V_1 = 2.4\ m^3/h$, $\rho_1 = 1027\ kg/m^3$, $C_{p1} = 3.93$ kJ/kg. °C, $\Delta T_1 = 25$ °C, $V_2 = 2.22\ m^3/h$, $\rho_2 = 998\ kg/m^3$, $C_{p2} = 4.18$ kJ/kg. °C.

So, the value of temperature difference can be calculated by Eq. (2),

$$\Delta T_2 = \frac{V_1 \times \rho_1 \times C_{p1} \times \Delta T_1}{V_2 \times \rho_2 \times C_{p2}} \quad (2)$$

$$\Delta T_2 = 26.14°C$$

So, the outlet live geothermal water temperature can be calculated as,

Outlet water temperature = 63 °C − 26.14 °C = 36.86 °C.

For heat exchange between milk and water in hot water tank can be expressed by the main basic heat exchanger Eq. (3)

$$Q = U \times A \times \Delta T_m \tag{3}$$

where, Q = Heat transfer rate (kJ/ h), A = Heat transfer area (m^2), U = Overall heat transfer coefficient (kJ/h.m^2. °C), ΔT_m = Logarithmic mean temperature difference (°C).

Where, T_1 = Inlet milk temperature, T_2 = Outlet milk temperature, T_{w1} = Inlet water temperature T_{w2} = Outlet water temperature, As calculated from Eq. (2), the temperature for milk and water are as mentioned below, T_1 = 50 °C, T_2 = 75 °C, T_{w1} = 63 °C, T_{w2} = 36.86 °C.

Logarithmic Mean Temperature Difference can be calculated using Eq. (4),

$$\Delta T_m = \frac{(T_1 - T_{w2}) - (T_2 - T_{w1})}{\ln\frac{(T_1 - T_{w2})}{(T_2 - T_{w1})}} \tag{4}$$

$$\Delta T_m = 12.66^\circ C$$

Heat Transfer Area can be calculated as, The surface area of heat transfer can be calculated from Eq. (5),

$$A = 2 \times \pi \times r \times h \tag{5}$$

where, r = 0.125 m, h = 0.45 m, from Fig. 3. So, A = 0.3534 m^2

To calculate, Heat transfer rate, the overall heat transfer coefficient can be calculated from Eq. (6),

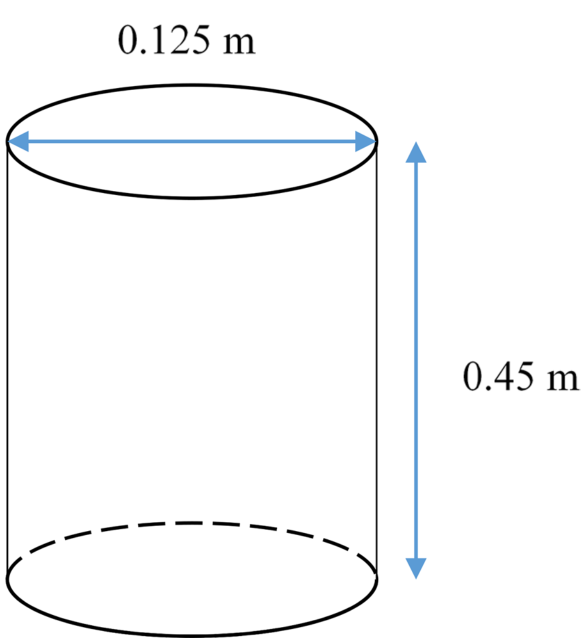

Fig. 3 Dimensions of heating tank

$$U = \frac{V \times \rho \times C_p \times \Delta T}{\Delta T_m \times A} \tag{6}$$

where, U = Overall heat transfer coefficient (kJ/h.m^2. °C), V = Flow rate of milk (m^3/h), ρ = Density of milk (kg/m^3), C_p = Specific Heat of milk (kJ/kg. °C), ΔT = Temperature change of milk (°C), ΔT_m = Logarithmic mean temperature difference (°C), A = Heat transfer area (m^2).

The values of above mentioned parameter are, V = 2.4 m^3/h, ρ = 1027 kg/m^3, C_p = 3.93 kJ/kg. °C, ΔT = 25 °C, ΔT_m = 12.66 °C, A = 0.3534 m^2

So, Overall Heat Transfer Coefficient (U) is calculated with Eq. (6)

$$U = 54127 kJ/h.m^2 {}^\circ C$$

The heat transfer rate can be calculated by Eq. (3). The values of parameter are as follows, A = 35.34 m^2, U = 54127 kJ/h.m^2. °C, ΔT_m = 12.66 °C. So, Heat transfer rate for milk pasteurization unit for heating is,

$$Q = 242166.57 \text{ kJ/h}$$

$$Q = Q_{act} = 67.26 \text{ kW}$$

Q_{act} is the actual heat transfer of the system. Q_{max} is the maximum possible heat transfer for the exchanger. The maximum value could be attained if one of the fluids were to undergo a temperature change equal to the maximum temperature difference present in the exchanger, which is the difference in the entering temperatures for the hot and cold fluids. Q_{max} can be defined by Eq. (7), where ∈ depicts the heat exchanger effectiveness,

$$\in = \frac{Q_{act}}{Q_{max}} \tag{7}$$

Let's assume G for m × C_p. The values for milk and water heat exchange can be calculated by Eq. (8) and Eq. (9),

$$G_{milk} = m_{milk} \times C_{pmilk} \tag{8}$$

$$G_{water} = m_{water} \times C_{pwater} \tag{9}$$

The values of parameter are as follows, m_{milk} = 2400 kg/h, C_{pmilk} = 3.93 kJ/kg. °C, m_{water} = 2220 kg/h, C_{pwater} = 4.18 kJ/kg. °C, Out of G_{milk} and G_{water} values, the lower value is depicted as G_{min} and the higher value is depicted as G_{max}. In case of milk pasteurization unit, G_{min} = G_{water} = 9279.6 kJ/h. °C. And, G_{max} = G_{milk} = 9432 kJ/h. °C.

The effectiveness of heat exchanger can be defined as shown in Eq. (10),

$$\in= \frac{1 - exp\left(-\frac{UA}{G_{min}}\right)\left(1 + \frac{G_{min}}{G_{max}}\right)}{\left(1 + \frac{G_{min}}{G_{max}}\right)} \tag{10}$$

Ratio of UA/C_{min} indicates the size of the heat exchanger, is also known as the number of transfer units (NTU) as shown in Eq. (11),

$$NTU = \frac{UA}{G_{min}} \tag{11}$$

The values of parameter are as follows, U = 54127 kJ/h. m^2. °C, A = 0.3534 m^2, G_{min} = 9279.6 kJ/h. °C. So, the value of NTU can be derived from Eq. (11),

$$NTU = 2.06$$

So, Eq. 10 can be written as Eq. (12),

$$\in= \frac{1 - exp(-NTU)\left(1 + \frac{G_{min}}{G_{max}}\right)}{\left(1 + \frac{G_{min}}{G_{max}}\right)} \tag{12}$$

The values of parameter are as follows, NTU = 2.06, G_{min} = 9279.6 kJ/h. °C, G_{max} = 9432 kJ/h. °C. The value of heat exchanger effectiveness is calculated from Eq. (12),

$$\in= 0.49$$

i.e., the effectiveness of heat exchange during heating is 49%. The maximum possible heat transfer Q_{max} for the system is calculated to be 137.28 kW.

Working of milk pasteurization unit

Pasteurization occurs in a sequential procedure, beginning with heating milk to a specific temperature, followed by chilling and storage. The flow chart in Fig. 4 depicts the order of milk pasteurisation in the Geothermal aided setup unit.

Heating process

The unit includes a storage tank, a hot tank with an insulating jacket, and an electrometer flow motor connected in a loop. The hot tank contains milk which is stirred by a gear motor at a controlled and adjustable speed, creating a perfectly heated blend.

i. Heating using live geothermal water

Figure 5 is schematic representation for pasteurization in case of availability of live geothermal water. Live geothermal water enters the loop at temperature T_2 through valve V_1 and exits at temperature T_3 through valve V_2, with valves V_3 and V_4 closed. It circulates in the insulating jacket of the hot tank. Electromagnetic flow meters measure the process flow using Faraday's Law of electromagnetic induction (Galili et al., 2006). Geothermal water continually circulates through the loop and keep the hot tank's temperature T_{C1} between 72 and 75 °C. A lower temperature water can raise milk to high temperature only when both liquids are in unstatic state i.e. are continuously moving, as in our case. This happens because the fluid in outer shell attains kinetic energy which provide us the extra temperature and minimizes heat loss (Fig. 6).

ii. Heating using a secondary water source

This setup provides an alternative for lab demonstrations, when live geothermal water is unavailable as shown in schematic representation using Fig. 7. A storage tank is filled with water from a secondary source is equipped with heater to reach desired temperature T_1. Passing through V_3 valve, stainless steel water pump and electromagnetic flow meter it reaches the hot tank insulation jacket and returns back via the V_4 valve. This system is an efficient and cost-effective way to demonstrate lab experiments without relying on geothermal water. The unit is intended to precisely control milk pasteurization time. Temperature is monitored and controlled in the hot tank using TC_1. Once the pasteurization process is complete, the solenoid valve opens to transfer the milk to the cold tank. As an alternative, milk can be drained through the available drain outlet.

Cooling process

A food-grade certified SS milk pump, Thermostatic Expansion Valve (TXV), Condenser with Fan, and Compressor are involved in the cooling cycle of the milk pasteurization. Figure 8 is schematic representation for cooling cycle of pasteurized milk. Hot milk is available in a Cold tank at 75 °C circulating through the Pump while fluid flows through the condenser and can be controlled by a thermostatic expansion valve. PHE acts as heat exchange element between milk and the fluid. Temperature sensors T_5 and T_6 indicate the input and output temperature of the plate-type heat exchange. Milk circulates in the loop until it reaches 4–7 °C, indicated by T_{C2} connected to the cold tank. This fluid flows through the condenser and can be controlled by a thermostatic expansion valve.

Cleaning process

The unit requires cleaning at the end of the pasteurization. It is a crucial step for hygienic reasons and to maintain good energy efficiency in the heat exchangers. This

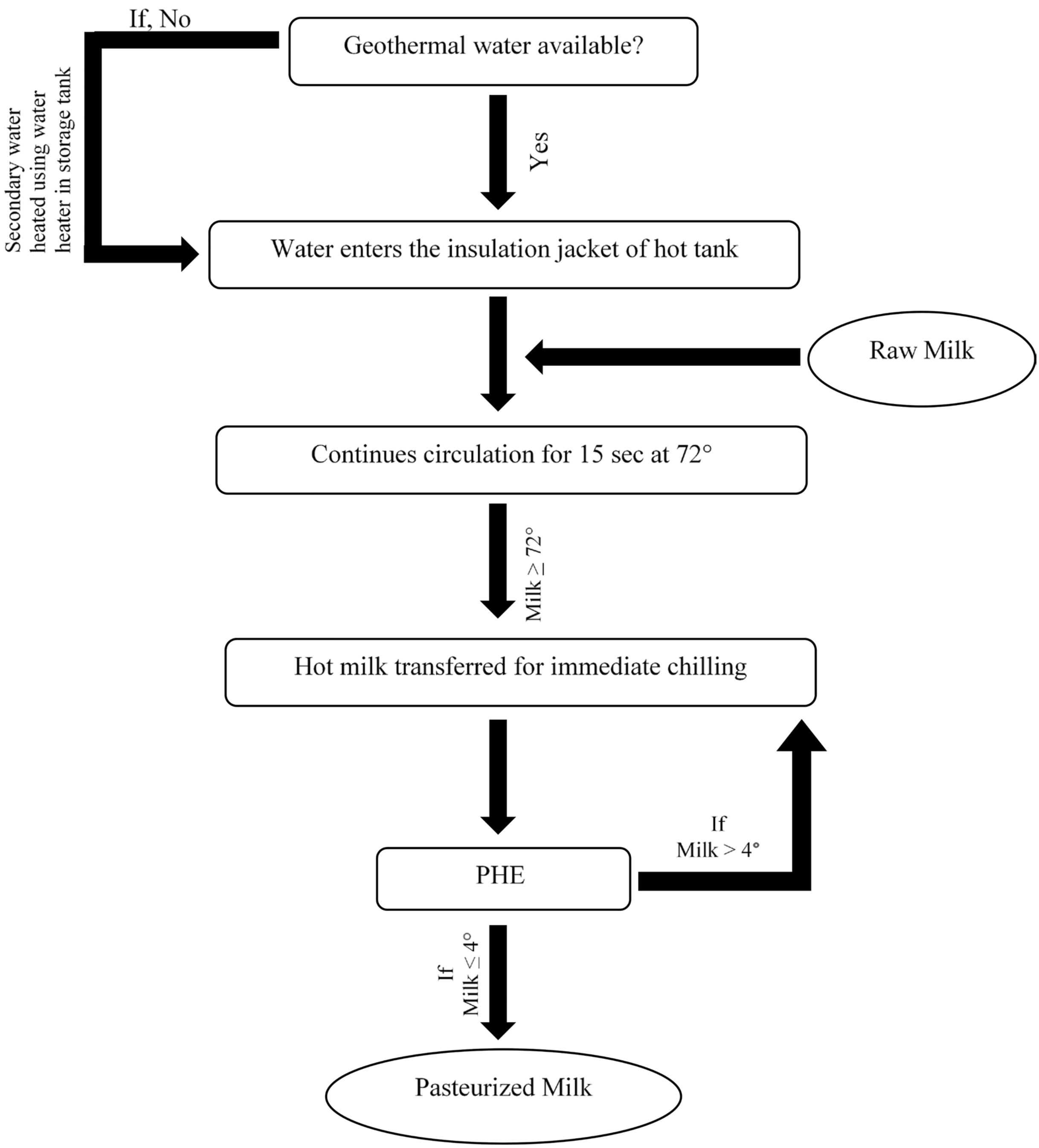

Fig. 4 Schematic flow chart for the working of geothermal aided milk pasteurization unit

is because, during pasteurization and storage, milk particles stick on the surfaces of the equipment and could harbor bacteria and other harmful microorganisms (Kiruja, 2012).

A touchscreen-based automated HMI and PLC system provides a simplified solution for milk production. The system automatically stores data on a pen drive using a USB port, and the schematic diagram is shown on the HMI main screen together with live data and flow visualizations. This system can be administered and controlled remotely from a variety of devices via Ethernet and Wi-Fi, which is even more practical.

Sampling

For the initial batch of testing, sample of pre pasteurized (raw milk) and post pasteurized milk were collected.

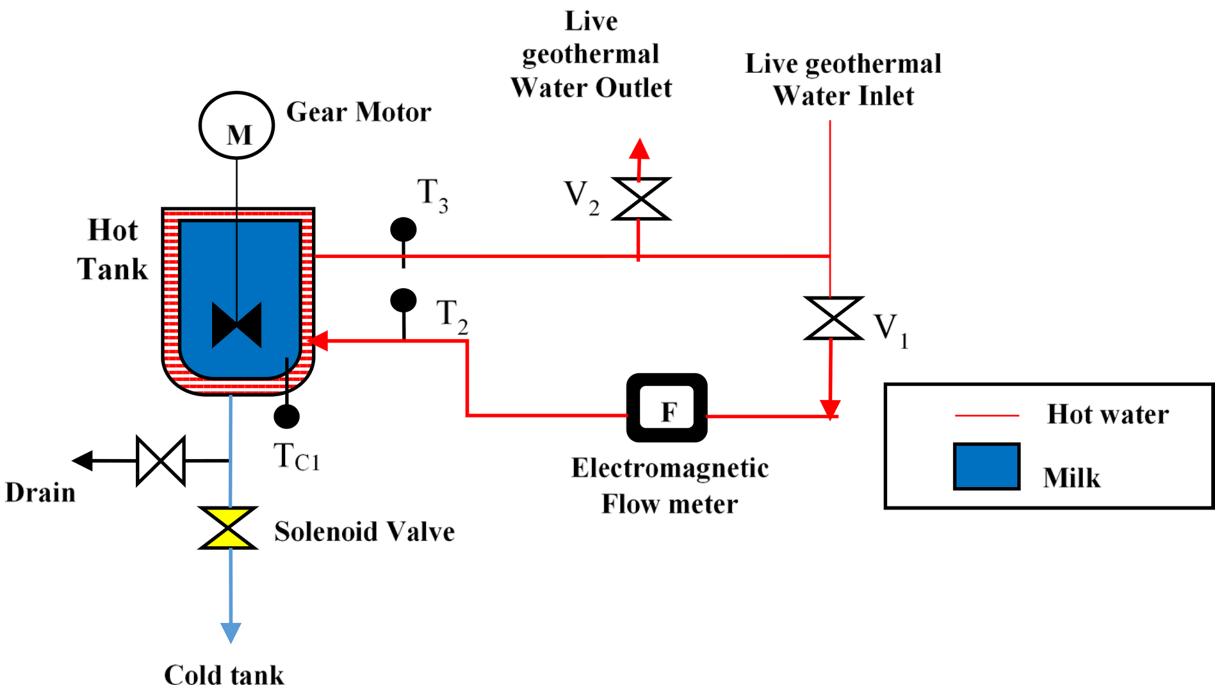

Fig. 5 Schematic diagram for heating using live geothermal water

Fig. 6 Geothermal assisted milk pasteurization system demonstrated in field

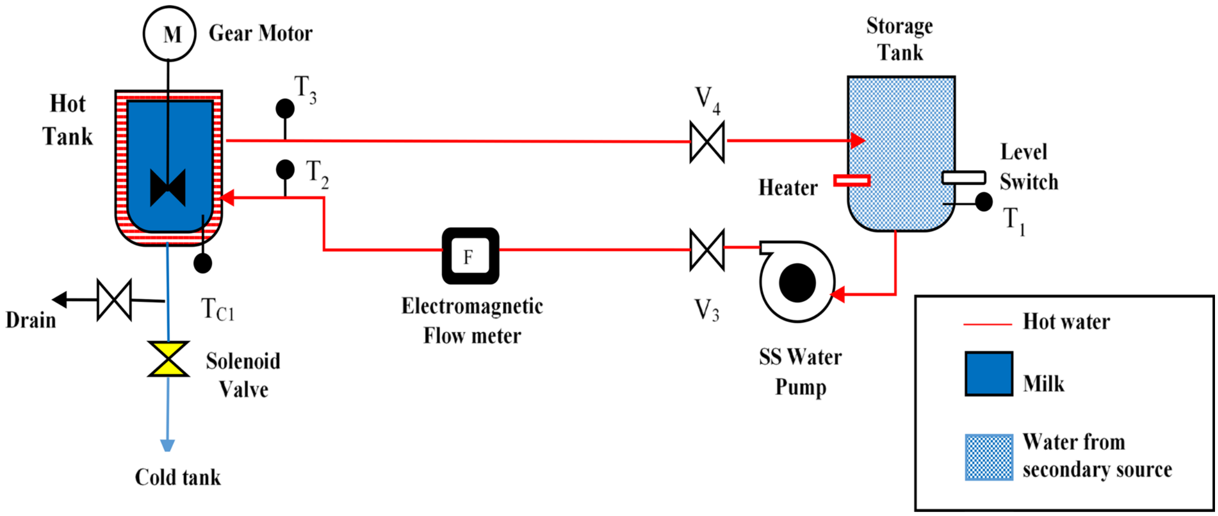

Fig. 7 Schematic diagram for heating using secondary water source

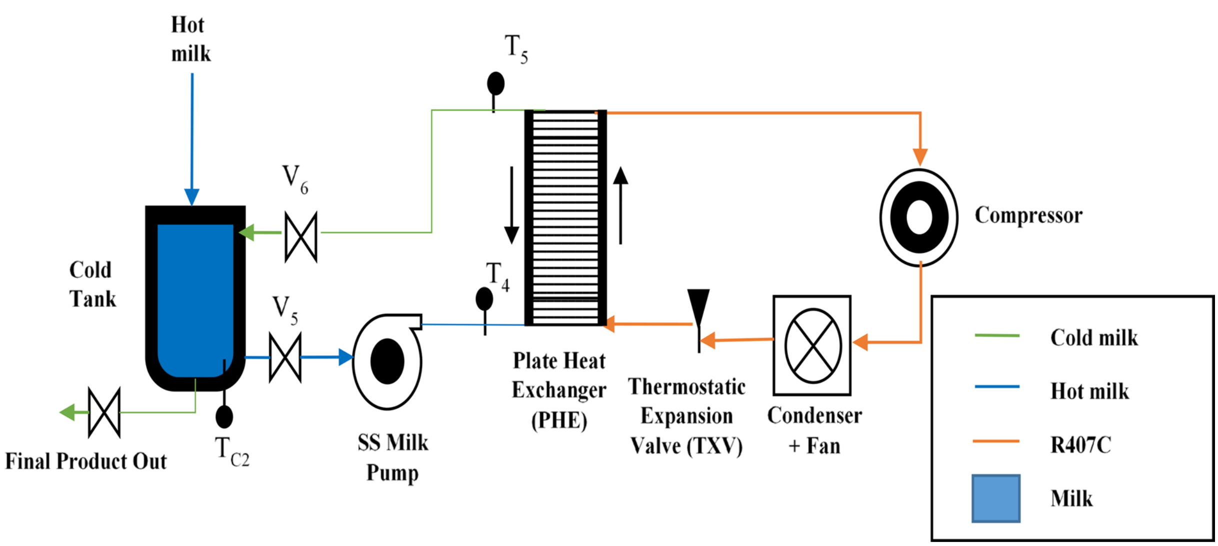

Fig. 8 Schematic diagram for cooling of milk

The pre pasteurized milk sample was collected at 25 °C and stored at around 10–12 °C. The post pasteurized milk sample was collected at 5 °C and was also stored at around 10–12 °C. A sample of 200 ml of milk was obtained and sent to the laboratory for testing.

Assessment of milk quality of geothermal-assisted pasteurized milk

Milk quality is a priority for consumers because of several health concern that might occur as result of milk contamination during handling, processing and storage (De, 2005; Karmaker et al. 2020) due to which pasteurization process is carried out. Pasteurized milk's flavour is generated from several processes that occur during heat processing or storage, which also affect colour (Schamberger & Labuza, 2007). The nutritional content and flavour of dairy products influences customer acceptability, shelf life, and other properties (Drake et al., 2006; Kühn et al., 2006). To alleviate our concern, several tests were conducted on Geothermal-Assisted pasteurized milk. They were classified as: Microbiological and Chemical

Fig. 9 Milk samples collected after pasteurization for quality assessment

tests. Figure 9 shows the samples of milk collected after pasteurization for quality assessment.

Microbiological test

Common pathogenic microbes in milk include *Salmonella* sp., *Listeria monocytogenes*, *Campylobacter jejune*, *Staphylococcus aureus, Escherichia coli*, etc. *and* these are responsible for many of food-borne diseases (Karmaker et al. 2020, Anderson et al. 2011) for which standard microbiological test like *Total Plate Count, Coliform Test, E. coli Test, Yeast and Mold Test*, were done to assess the microbial burden (Indumathy et al., 2020) in milk pasteurized utilizing a Geothermal water. The result of these test were found to be satisfactory. Geothermal-supported approach was successful in lowering the microbial burden in milk, with bacterial counts reduced by up to 99%. As can be seen from Table, before pasteurization the total plate count was around 69,000 cfu/ml and after pasteurization it was reduced to 28,000 cfu/ml well under the limit of WHO standard. Coliform, Yeast and Mould count in milk before and after are found to be under standard WHO limits. Furthermore, it can minimize food waste related to milk by enhancing its shelf life and by eradicating food-borne pathogens.

Chemical test

For the assessment of pasteurized milk, the chemical tests were done to ensure milk's nutritional value. These were pH, turbidity, Heavy Metals Test, Chemical Residue and contaminants test. Chemical test results were found to be under standard values which presumes milk to be safe for consumption. Heavy metal and chemical residue and contaminants were found to be absent. Additionally, the milk was found to be relatively resistant to spoilage, further demonstrating its quality.

Societal benefits and techno-economic aspect and of geothermal assisted milk pasteurization unit

The successful design and implementation of geothermal-assisted milk pasteurization equipment require careful consideration of the energy efficiency of the system. It is durable, with a selection of materials that are resistant to corrosion, have high heat resistance, are easy to clean and maintain. It ensures the safety of all operators, customers, and milk products through the use of safety features such as over-temperature protection, emergency shut-off, and appropriate guarding. Economic value to the project accrues from the energy generated from the direct use of heat. Research into field is required to determine the financial viability assessment of geothermal energy utilization in terms of direct and indirect employment due to the variability in resource quality at a certain site (Shortall et al., 2015). This will maximize the potential benefits of this technology.

Social acceptance is an important factor when designing geothermal-assisted milk pasteurization equipment. The system must be designed with safety and environmental concerns in mind. This includes considering the potential for emissions, water use, and other impacts on the local environment. The safety of the equipment must also be taken into account when designing geothermal-assisted milk pasteurization equipment. The system must be designed to minimize the risk of accidents, including risk for scalding and burns. Geothermal energy has the potential to reduce carbon footprint. The design of geothermal-assisted milk pasteurization equipment must take the potential impacts into account and strive to minimize them.

Discussion

Pasteurization of milk is a crucial step in ensuring the safety of milk used for human consumption. Uniform heating is necessary to produce safe milk for customers; for this purpose, several time and temperature combinations, such as sterilisation, HTST, LTST, etc., exist. Different sources can be used for heating, however the emphasis should be on sustainable and affordable resources. Geothermal energy, a green energy, so proved to be a wise decision. Geothermal-assisted milk pasteurisation, a cutting-edge and eco-friendly technique, is now being used to heat and pasteurise milk without the need for additional energy sources, making it a desirable alternative for those looking to reduce impact on the environment. For the first time, geothermal energy is being utilised to pasteurise milk in Gujarat. The novelty of this unit is that it exhibits direct application in the form of milk pasteurization by utilizing rejected geothermal water from power generation system.

The designed unit is hybrid and employs variety of resources in the heating and cooling processes. The unit's operating principle is to achieve the appropriate temperature for milk pasteurisation by using geothermal water from our self-flowing well in Unai village. It is of the HTST type, which means that it takes short time to heat the milk particles evenly, with a 49% efficiency of heat exchange. To build a sturdy unit, simple components like pumps, valves, tanks, compressors, and condensers that are already on hand are used. This will guarantee that unit maintenance and repair are simple, lowering any additional setup-related expense. For chilling of milk, refrigerant which can be operated at relatively low pressure is utilized. PHE is employed for heat exchange between hot milk and refrigerant.

To evaluate the performance of the unit, testing was performed at our drill site in Unai village, and raw milk and pasteurised milk samples were compared using laboratory tests. The results of the microbiological and chemical testing were deemed satisfactory. The unit was effective in lowering the total plate count from 69,000 to 28,000 cfu/ml, and the chemical test findings were within WHO guidelines. The turbidity and pH readings were 6.72 and 0.85NTU, respectively.

Not only ensuring safe milk, Geothermal-assisted milk pasteurization unit design has the potential to provide a wide range of social benefits. The rejected water from the unit can be utilized for direct applications like salt and base metal production. Furthermore, unit will help reduce the amount of greenhouse gas emissions generated from dairy production, which can have drastic effect on the environment. Geothermal-assisted milk pasteurization units require less energy to operate, which can lead to lower operational costs for dairy farms. This allows dairy farmers to pass the cost savings on to consumers in the form of lower prices, making dairy products more accessible to those with lower incomes. The decrease in conventional energy consumption can help reduce dependence on non-renewable energy sources. Therefore this unit will improve the safety and accessibility of dairy products.

Conclusion

The design of geothermal-assisted milk pasteurization equipment is an important consideration for dairy-based industries, as it can provide a cost-effective, energy-efficient solution for food safety and quality assurance. The present unit incorporated proper thermal control, efficient heat transfer, and safety features to ensure that the equipment operates safely and effectively. The hybrid unit employs hot tank with insulation jacket for heating the milk and VCR components for chilling the milk. The heat exchange rate for the unit is 49%. The design proved efficient in heating and chilling milk, resulting in safe pasteurized milk, as determined by a comparison test between samples of pre and post pasteurization. The unit was successful in reducing total plate count from 69,000 to 28,000 cfu/ml while chemical test shows the pH and turbidity values were good. Heavy metals and chemical residue and contaminates were absent in our tested samples. With the right design considerations, geothermal-assisted milk pasteurization equipment can provide a reliable and cost-effective solution for dairy-based industries. The results demonstrate that geothermal-assisted pasteurization is an effective and sustainable method for producing quality milk. This process has the potential to provide a reliable, high-quality source of milk that could benefit both consumers and the environment.

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NB, PV, TK and VP worked on drafting and conceptualization of the manuscript. M, SS, RP worked on the acquisition of data, instrument testing and analysis. RK, KY, AS worked on revision, editing and correction of the manuscript.

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Availability of data and materials
All available data and materials are incorporated in the manuscript.

Declarations

Competing interests
The authors declare no competing interests towards the current work.

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