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A Review on Solar Water Heating Systems and its Use in Dairy Industry

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A B S T R A C T

Currently in India milk processing is more than 30 % of the total milk production. Since long the Indian dairy industries relies on the non-renewable sources of energy, which not only getting more and more expensive but also are responsible to serious health concerns and environmental problems such as global warming. Therefore, adoption of green energies has been promoted by research communities, social and environmental groups and government. Considering the geological location of India, solar energy has been proven most promising among the available green and renewable energies. The requirement of energy intensity and temperature range in milk processing operations are amenable for adoption of solar energy.

Introduction

Energy is an essential factor for economic development of any industry and thus any country (Kapoor *et al.*, 2014). India is advancing toward becoming a developed nation and it is observed that energy consumption has increased by 6% approximately for last two decades. The need for the ease of availability of services and goods has challenged the entrepreneurs to fulfill the demand of consumers. This is applicable to all sectors of industry including dairy industry. The current Indian milk production is 176.4 Million Tons per year, which is 7.8% of world milk production (Dutta, 2011; Panchal *et al.*, 2010; DAHDF, Ministry of Agriculture, GoI). The demand for milk is expected to increase in near future due to population explosion, increased spending power and diversification in dairy products. Dairy cooperatives play very significant role in the procurement, processing and marketing of milk, dairy products and in representing farmers at state and national levels (Fenoll, 2002). India rank 5th in the world with 49% of total energy is consumed in industry purposes. Currently an import for energy sources is 9 % for coal, 77 % for crude oil and petroleum and 31 % for natural gas (Desai and Zala, 2010, Desai *et al.*, 2013). Today, the heat generation at power station utilizes primary fossils fuels, which are non-renewable. An alternative source is immediately required, which is renewable and non-pollutant so that it could be exploited as much as needed without having any adverse effect on environment. One such technology is solar water heater (Date, 2010). Present usage of different renewable energy include, solar energy (1%), wind energy (0.5%), biomass energy (43%), hydropower energy (50%) and geothermal energy (5%) (Desai *et al.*, 2013). The present paper mainly focuses on solar energy. The solar flux density (irradiance) reaching in all regions of earth is nearly 1 kW/m^2 but in Indian terrain, we receive 5 to 7 kWh/m^2 of solar energy for 300 to 330 days in a year, which is sufficient to set up 20 MW (Dhotre *et al.*, 2012). Utilization of this tremendous solar energy may help to mitigate world energy crisis and address pollution related problems.

In India an approach can be made to utilize this energy in cost effective manner in dairy, food and agriculture industry (Chauhan and Rathod, 2018) for operations like cooling, heating, pasteurization, lighting, steam generation, etc., (Jenkins, 1995; Desai, 2013). The hot water produced by the solar collectors can be used in Low temperature processing (LTPs) (below 80°C) (Veerabonia and Ratnam, 2012) as well as high temperature processing (HTPs) (above 100°C) which are bottle washing, pasteurization (72ºC/15sec), CIP (70-80°C) (Cleaning in place) and sterilization (121ºC/15min), UHT (150ºC/no hold) (Ultra high temperature), multiple stage evaporation, spray drying, respectively (Sandey and Agarwal, 2015). Several attempts have been made to apply this technology for milk processing. Franco *et al.* (2007) designed a milk pasteurization system 10 L capacity using Fresnel type concentrator with a vaporizer located in the focus. The steam was produced in an isolated container where the milk was heated by a double boiler. Zahira *et al.* (2009) fabricated a solar milk pasteurizer to operate and tested it from 65 to 75˚C. They concluded with possibility of cost benefit by eliminating the non-renewable energy requirement.

Construction and working

In general, a solar water heating system consists of *a collector*, *an insulated tank*, *a pump*, *one or two heat exchangers* and a *control system* (Yadav *et al.*, 2016). The collector absorbs the solar radiations falling on it and transfers it to working medium flowing through it. The heated working fluid is stored in an insulated tank until required for use. The pump affects the transfer of working fluid through heat collector and heat exchanger from where the working fluid gives solar heat to the process. Control system is generally the thermostat or valve that ensures the operation of the system in controlled manner. The processes of collection transfer and storage, being main operations in solar water heater (Hadiya and Katariya, 2013) are explained below.

Collector

It has a dark surface generally made up of metal, to absorb radiation from the sun and conduct it to the thermic fluid, also known as working fluid. The collector is usually insulated with 2.8-8.0 cm thick insulation to prevent loss of heat to environment. The collector assembly is covered by glass or plastic which permits the entry of short waves but opaque to longer infrared radiations reflected from absorber. The glass cover usually has thickness of about 4-5 cm and heat gets trapped between glass cover and absorber plate like greenhouse effect. The absorber plate usually has thickness of 0.2 - 0.7 mm, diameter 1-1.5 cm and the pith 5-12 cm. Absorber material must have higher thermal conductivity, higher strength and resistance to corrosion. Copper is most preferable due to higher thermal conductivity (385 W/mK) (Verma *et al.*, 1987). There are different collectors based on glazing effect, reflectivity and transparency at various wavelengths, heat retention and life expectancy (Beardmore *et al.*, 2008). The classification of collector is shown in Figure 1 and few of them are discussed below (Hadiya and Katariya, 2013).

Flat plate collector

Flat plate collector uses thermal absorber having an area of 1.5 - 3.0 square meters in a single enclosure. The assembly is placed inside a waterproof insulated housing, with insulation underneath the plate to prevent heat loss to roof. Insulating materials must be selected to withstand temperature of 300°C so that the panel can withstand exposure to direct sunlight with no thermal load, known as 'stagnation' (Hadiya and Katariya, 2013). The flat plat collectors are of two types:

Liquid flat plate

The mode of heat transfer in liquid filled flat plate is conduction. In this thermal conductivity is important factor which states the rate of heat transfer. But in air filled flat plate heating thermal conductivity is not an important parameter. In liquid containing flat plate collector corrosion is more in comparison to air type.

Air filled flat plate

Similar to liquid filled flat plate collector but in this air is used as working fluid (Hitesh *et al.*, 2018). These are further classified into following types:

Porous type

Air stream flows through the absorber plate. Cooled air stream is introduced from the upper surface and passed through porous absorber plate. Porosity provides higher heat transfer surface and provides more residence time due to friction inside pores. Hence, it reduces the heating time but pressure drop is higher. Some of the examples of porous types collectors are: Slit or expanded metal, Transpiered honey comb, Broken bottle and Overlapped glass type.

Non-porous type

Air stream flows over the absorber plate. Heat exchange occurs at the surface only, thus it rate of heat exchange is comparatively less but storage time in such units is quite more. These are further classified into Simple flat plate, Finned flat plate and V-corrugate.

Concentrating type

It is installed when high temperature is required. This is achieved by concentrating high intensity solar radiation on absorbing surface. It uses optical system in the form of reflector or refractor.

In reflecting type mirror is used while in refracting type Fresnel lens is used. Radiation is concentrated on the smaller area such that radiations get magnified form 1.5 or 2.0 to 10,000 times as a result the fluid passes can be heated to a temperature of 500ºC. These are of following types:

Focusing type

This optical system focuses the solar radiation on to the absorber. These collectors are Line-focusing and Point-focusing types, which can achieve temperature of 150-400°C and above 500°C, respectively.

In Line-focusing type, the solar radiation is focused on the pipeline carrying thermic fluid, whereas, in Point-focusing type, solar radiations are focused on small volume (point) through which thermic fluid flows.

Non-focusing type

It is modified plate type and the rays are allowed to fall on absorber using reflection in mirror. These are classified as: Flat Plate collector with plane reflector and Compound parabolic concentrator.

Energy balance equations

The various energy balances in solar water heater has been presented according to Kalogirou (2004), ASHRAE (2005), Hadiya and Katariya (2013). The detail structure showing various loses and gain of heat energy is shown in Figure 2.

Heat delivered by collector (Under steady state condition): $H_T.A_c.(\tau\alpha)_e = Q_u + Q_L$

Total energy absorbed by plate : $H_T(\tau\alpha)_e$ $H_T(\tau\alpha)_e$

(Hadiya and Katariya, 2013; Sethupathi *et al.*, 2017)

Total heat loss from collector plate : $Q_L = A_L U_L (T_P - T_a)$ (Hadiya and Katariya, 2013)

Rate of heat collected from collector :

$$Q_u = A_c[H_T(\tau\alpha)_e - U_L(T_P - T_a)] \quad \text{--eq. (1)}$$

Where, $(\tau\alpha)_e = \dfrac{\tau\alpha}{1-(1-\alpha)\rho_d}$ and,

H_T = Solar radiation incident on collector per unit area and time, (W/m^2)
A_c = Collector area, m^2
Q_u = Rate of useful heat collected from collector, W.
Q_L = Rate of heat lost from the collector, W
$(\tau\alpha)_e$ = Effective transmittance - absorptance and diffusion resistance.
τ = Fraction of incoming solar radiation that reaches the absorbing surface.
α = Fraction of solar energy that reaches the surface.
U_L = Overall heat loss co-efficient (W/m^{2}K).
T_P = Average temperature of upper surface of absorber.
T_a = Atmospheric temperature.

Heat removal factor (F_R)

It is the ratio of actual heat energy collected to useful energy collected, if the entire absorber surface is at the temperature of fluid entering the collector.

$$F_R = \frac{mC_p}{U_L A_C}[1 - \exp(-\frac{U_L A_C F_P}{mC_p})]$$

Considering heat removal factor then equation eq. (1) becomes:

Net Rate of heat collected from collector: $Q_u = F_R.A_c[H_T(\tau.\alpha)_e - U_L(T_i - T_a)]$

Collector efficiency:

$$\eta_c = \frac{\textit{Actual useful energy collected}}{\textit{Solar radiant energy incident on collector}}$$

(Nielsen Pederson, 2001)

$$\eta c = \frac{Q_u}{H_T A_c} = F_R(\tau\alpha)_e - F_R U_L \frac{(T_i - T_a)}{H_T}$$

Where,
F_p = Flat plate collector efficiency factor.
M = Mass flow rate (kg/s)
C_p = Specific heat of fluid (KJ/kg°C) (for milk 3930 KJ/kg°C) (Walstra *et al.*, 1999)

Transfer

The circulating fluid transfers the energy to storage tank using natural or forced circulator.

The pipe is made up of either copper, aluminum or steel. The copper is preferably used due to its high thermal conductivity (385 W/mK) which allows the faster heat transfer from the absorber to the storage tank. Fluid used in the pipelines attached to the absorber is either water or aqueous glycol solution that can be used for sub zero temperature processing. The similar concept was given by Nielsen and Pederson (2001). The heat transfer from the working fluid (recirculating in collector) to the main fluid (storage tank) is done by heat exchanger.

Storage

Hot water is stored until it is needed at a later time in a room or on the roof in the case of thermo-syphon system. The main cost of solar thermal systems comes from the collector field (54%), the storage tank and the heat exchanger (24%). It is a solar water heater system that uses the thermal energy of the sun to heat water. They are usually aimed at heating water to a temperature hot enough for dairy processing like pre-heating (45ºC) and pasteurization (72ºC/15 sec) of milk. The collector consists of number of pipes covered with back color to absorb the heat energy and added in tank to store heated water in it (Atia *et al.,* 2015). Tank is insulated to prevent heat loss. Water is cycled through collector several times to raise the temperature. The water can be passed using thermos-syphon effect (Passive heating system) or using forced circulatory pump (Active heating system). In thermos-siphon effect hot water rises above cold water due to density difference (Yadav *et al.,* 2016). During sunshine water will circulate and become hotter but at night reverse happens and losses it heat to environment. To avoid this edge of collector is kept 0.3 m below the tank. Recently, number of chemicals or mixture of chemicals have been used as storage materials instead of water, called as Phase Change Materials. These chemicals have their melting points in the desired range of temperature (Hadiya and Katariya, 2013). Thus, they can store latent heat of fusion, which reduce the storage space requirement and also enable the process operation within narrow range of temperature without much drop in temperature. However, Phase-Change Materials (PCM) are out of the scope of this paper and hence, not described further.

Advantages of solar water heating system

Its operating cost is zero.
It does not produce noise or vibrations.
It cannot produce shock or set fire to house.
It is completely pollution free and could give a big saving in terms of fossils fuels.

Calculation for the yield of a solar energy

To calculate this it is necessary to know the amount of radiation available at the location of the system, its variation in time and the ratios of diffuse and direct parts. Solar radiation is converted into other forms of energy, can be divided into thermal and non-thermal systems.

Thermal systems

The thermal systems include transformation of solar radiation into heating, into cooling or into mechanical energy. In all thermal systems solar radiation is first transformed into heat on surfaces exposed to this radiation. The collector collects the sunlight and converts to heat energy (Yadav *et al.,* 2016):

Heat absorbed by collector (Q_n) :

$$Q_n = (1-g).a.Q - Q_{rad} - \frac{Q_{cond}}{A}$$

Radiation heat losses (Q_{rad}) :

$$Q_{rad} = \sigma \varepsilon_P T_P{}^4 T_g^4$$

Efficiency of collector :

$$n = \frac{Q_n}{Q} = a(1-g) - c\frac{\Delta T}{Q}$$

Where, $\sigma = 5.76\times10^{-8}$ W/m^2K^4
ε = Emissivity of plate
T_p = Absorber plate temperature (K)
T_g = Surrounding air/glass cover temperature (K)
Q_n = Net heat absorption
Q = Solar radiation density normal to the collector plate (W/m^2)
g = Reflection or absorption loss in cover plate
a = Absorption coefficient for solar radiation of a black body
Q_{rad} = Radiation heat losses (W/m^2)
Q_{cond} = Conduction heat losses (W)
A = Absorption surface (m^2)

Applications of solar energy in dairy industry

Refrigeration

Refrigeration is the process of removing heat from a product at lower temperature and discharging that heat to the ambient temperature with the help of external work. In dairy plants, refrigeration section consumes around 30% of the total electricity consumption of the plant (Dhotre *et al.*, 2007), hence energy saving in refrigeration can greatly reduce the energy costs of any dairy plant. Use of Vapour-Absorption Refrigeration system working partly on solar water systems has been tried in some dairies. The system is composed of medium temperature collector, single effect water ammonia absorption chiller and cold storage. It also used to run a vapor absorption system for refrigeration plant for maintaining cooling system. A power stored in battery at use for the run an air conditioner (Ishaku, 1990, Desai *et al.*, 2013). One such system was manufacture by Ayadi *et al.* (2008) in, which chilled refrigerant temperature is about -5°C and the condenser temperature /ambient temperature is about 35°C. It is Vapour-Adsorption Refrigeration System.

The system consists of two containers connected by a tube and cycle comprises of regeneration and refrigeration. One container (Let us say A) contains absorbent and refrigerant. This absorption of refrigerant is exothermic reaction (heat generates), whereas desorption is endothermic (heat absorbed). When heat is supplied to container A also called as generator, the refrigerant is vaporized (generation phase), leaving behind a "weak" mixture of refrigerant and absorbent. The vaporized refrigerant passes to container B where it condenses and loses latent heat. During the generation phase container B operates as a condenser. The latent heat is usually removed by chilling the condenser with circulating water air. The condensation occurs without reduction of pressure. In refrigerating phase generator operates as absorber and the condenser (container B) as evaporator. During this phase the absorber is cooled by the ambient fluid which results in the fall of pressure. Under reduced pressure evaporation of refrigerant occurs in evaporator which receives latent heat by air, water or fluids. In this transfer of the "strong" mixture from absorber to generator requires external power. Various components are used in absorbent/refrigerant compositions. Those most often used are:

Flat Plate Solar Collector
Fan-Coil Unit
Cool Air
Warm Air
Storage Tank
Back-Up Boiler
Water Chiller
Cooling Tower
Absorbent (Lithium bromide/water, Water/ammonia, Calcium chloride/ ammonia) etc.

Heating

It works on the basis of the density inequality of hot and cold water or thermos-syphon. In colder countries, integrated collector/ storage Solar water heater collectors are more suitable for compensating sun radiation limitations in the evening and afternoon (Li, 2007). Solar thermal can be applied in milk for cleaning, sterilization, pasteurization and drying (Benz *et al.,* 1999). David Ciochetti (1983) that heating water to 66°C in a solar cooker will provide enough heat to pasteurize the water and kill all disease causing microbes.

Milk Pasteurization

The process pasteurization was discovered by Sir Louis Pasteur, which uses the application of heat to destroy human pathogens in foods. For the dairy industry, the terms *pasteurization* mean the process of heating every particle of milk to specific time temperature combination and held continuously at or above that temperature for at least the corresponding specified time. In milk concern two types of pasteurization process is common *i.e.,* LTLT (Low Temperature and Long Time) and HTST (High Temperature and High Time) which heating ad holding 63°C/30 min and 72°C/15 sec respectively (De, 1980; Aneja, 2002). The other types of het treatments given to milk are Vat pasteurization (63°C/30 min), Ultra pasteurization (138°C/2 sec) etc. (Watts, 2016). In relation to solar heating, attempts have been made by researchers to utilize solar energy for pasteurization of milk. Atia *et al.,* (2015) designed a pasteurization system that is based on the solar energy as a thermal source for pasteurizing the milk. A solar flat plate collector was used as milk pasteurizer. The pasteurization temperatures were 63 ˚C and 72˚C. The ability of milk pasteurization by solar energy has been tested by researcher using the system shown below in Figure 3 and process flow chart is shown in Figure 4. The milk is transferred from the tank into the solar collector having a surface area of 1.2 m^2 by gravity. The absorber is black colour painted to absorb maximum amount of solar radiation. The inner tube is of diameter 11mm thickness and 1.0 mm thickness. The movement of milk within the system was controlled by valves at certain points in the system. The outer part of absorber plate is covered by glass cover to protect from dust. It usually has thickness of 6 mm. The cover of glass wool from sides is required to reduce the heat losses. The milk flew at a low flow rate to reach the temperature of pasteurization after that it is passed to holding tube to hold 63˚C for 30 minutes and then forwarded to the cooling unit. The system can also be for HTST pasteurization processing *i.e.,* 72˚C for 15sec. Solar heater system could also be applied by providing the steam to regeneration section and then to main heating section of pasteurizer.

Steam generation

Low temperature steam is extensively used in sterilization. Parabolic trough collectors (PTCs) are high efficient collectors commonly used in high temperature applications to generate steam. PTCs use the steam flash, direct or in situ and the unfired-boiler. These are line focusing type concentrating collector. In this solar radiation is collected over area of the reflecting surface and is concentrated over parabola. The absorber tube is of stainless steel or copper blackened at the outside surface to increase absorption of radiations. In the steam-flash method, pressurized hot water is flashed in a separate vessel to generate steam (Kreetz *et al.*, 2000). Oil fired boiler is feed with normal water for the routine operation. On installation of solar water heater, the feed water of the boiler raised from 27°C to 67°C (BEE, 2010).

Drying

This system can be applied for evaporation of moisture from the milk to increase the milk total solids which thereby can be used for manufacturing of powders. In drying (removal of moisture) and dehydration (bone dry condition) systems the use solar energy is either for solely power supply to heat the air or as a supplementary energy source. Conventional drying systems burn fossil fuels for their performance but usage of this green energy would eradicate the environmental pollution. The initial cost of implementation is high but in the successive years it could be cheap and economic (Schnitzer *et al.,* 2007). The drying requires the inlet temperature of heated air 250°C and the outlet temperature 80°C. The flat plate and concentrating type collectors both are capable of providing the temperature of above 400°C and hence it can be used easily to process the milk for power preparation.

Paneer manufacturing machine

Paneer is an acid-coagulated indigenous milk product (De, 1980). At present the fuel given for the generation of steam in boiler is non-renewable sources such as coal or furnace oil which finally increases the environmental pollution CO_2 or methane component of atmosphere. Solar energy system is unlimited source of energy and it is free of cost because it is obtained by natural occurring phenomenon in sun. We can use this energy for dairy product preparations. One such product is paneer. It was observed that researchers have developed paneer manufacturing system using solar water heating system. In paneer manufacturing system the hot water outlet from collector was connected to surface heat exchanger to obtain hot water temperature of 80ºC. This hot water was further used for heating of milk during paneer manufacturing. Sahu *et al.,* (2016) prepared paneer and compared with control for their chemical, microbial and sensory characteristics. The experimental paneer had 51.73, 24.35, 48.27 and 0.49% moisture, fat, total solid and acidity respectively and was comparable to control. The total and coliform counts were 7.1 x 10^3 and 77 cfu/g; 6.2 x 10^3 and 69 respectively for experimental and control paneer samples and was within the BIS microbial standards specified for paneer. Solar water heating system was effectively used to produce good quality paneer without using fossil fuel

Fig.1 Classification of collectors

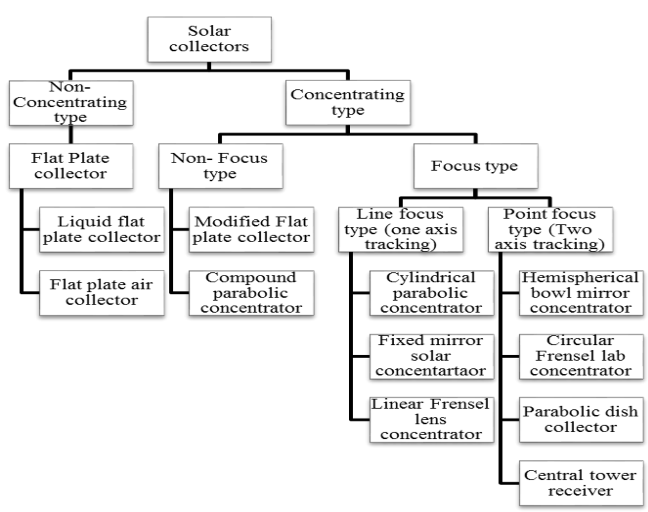


Fig.2 Heat transfer process in flat plate collector

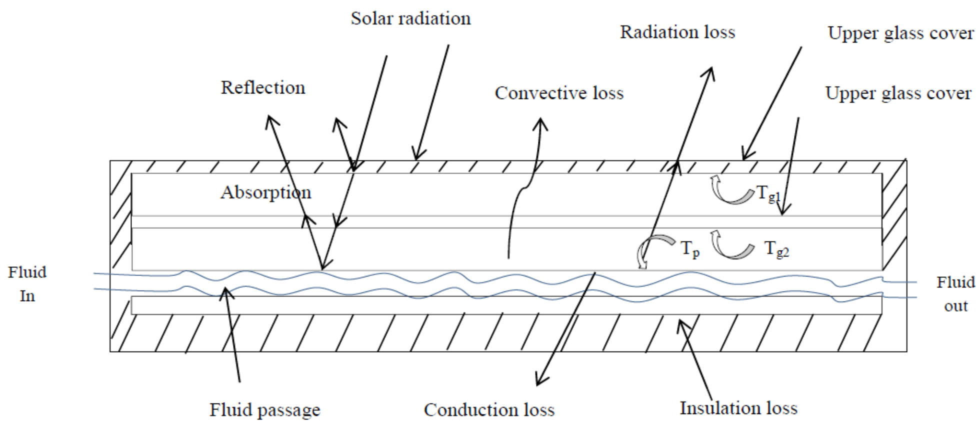


Fig.3 Solar system for continuous pasteurization

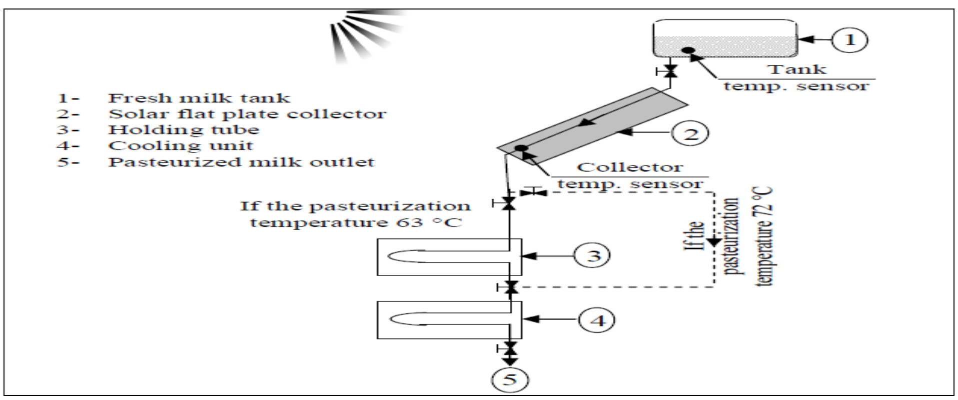
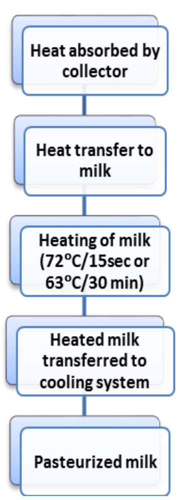


Fig.4 Process flowchart for pasteurization of milk



In conclusion, India lies in sub-tropical region and receives ample amount of sunlight almost round the year. Use of such huge amount of energy, which otherwise gets wasted, for productive purposes would not only make the environment safe but also bring economic benefits to entrepreneurs. The solar water heating plants can be used in dairy for the processing of raw materials to get the finished product. In dairy industry it has been used for pasteurization, sterilization, pre heating, paneer manufacturing, etc. The same can be replicated in other dairy and food processing plants and can also be implemented for other processing units considering present scenario.

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