Performance Study of Milk Pasteurization using Solar Reflectors

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Abstract – *It is the need of the hour to eradicate the issue of diseases that are linked to the consumption of harmful milk that leads to deaths of millions in the developing countries of Asia and Africa. Abundant renewable energy like Solar energy can be used to resolve the issue of milk contamination and contribute towards betterment of public health. In many remote corners of the society, there still does not exist a highly efficient mean of natural Milk Pasteurization. In this study, a low-cost Milk Pasteurization unit was fabricated to examine the potential of Solar energy in pasteurization milk inherently. Although raw milk can be pasteurized on the stove, it still proves to be an ineffective mean of pasteurization due to uneven distribution of heat. This paper enumerates the key features of the domestic pasteurization unit considering different parameters like ambient conditions and ergonomics. For this study, milk samples from ruminants like Cattle were taken to carry out the removal of microbes. This paper intends to help locals of the developing nations to consider safety measures and give them a performance overview of a practical milk pasteurization unit that they can easily install by themselves.*

Key Words: Solar Reflectors, Pasteurizer, Microbes, (ALP) Alkaline Phosphate, Parabola

1. INTRODUCTION

The pasteurization process is one of the most common treatments in the food industries in order to eliminate harmful pathogenic and spoilage microorganisms. The process consists of maintaining a high temperature established during a short period of time. The primary purpose of pasteurization is to increase milk safety for the consumers by destroying disease causing organisms or commonly referred to as pathogens that may be present in the raw milk. Another purpose is to increase quality of the milk by destroying spoilage micro-organisms and enzymes that result into reduced quality and harm the shell life of the milk. Milk, which is one of the most essential part of our nutritional liquid diet often contains harmful bacteria. Raw milk may still contain potential microbes if the milk is not sufficiently pasteurized using conventional methods. The harmful enzyme (ALP) Alkaline Phosphate which is present in the raw milk and responsible for intra-abdominal infection when consumed is successfully removed in the pasteurization process. Pasteurization also limits fermentation of the milk and annihilates all the disease producing pathogens. A proper range of temperatures and working time should be considered so as to avert the incomplete activation of microbes.

Today, the use of fuel has become expensive and also has been one of the major contributors to the growing problems of pollution. In areas whereas the sunlight is present in abundance, a small-scale natural milk pasteurizing unit may prove to be beneficial. Such easy, robust and energy-efficient alternatives can be developed for the communities of developing nations. Although the temperature of the pasteurization process can be controlled with classical control method, changes in the milk temperatures are observed due to external disturbances. To minimize the effect of these phenomena, a higher set point temperature was fixed in the experiment in order to avoid temperatures below the pasteurization temperature.

In this study, a Solar Reflector unit was fabricated to carry out Milk Pasteurization. The experiment was conducted using a range of temperatures from 60°C to roughly 75°C. The maximum ambient temperature during the experiment was close to 41°C. This study deals with the development of a model for a small-scale pasteurization unit based on physical principles. The incorporation of different elements to this prototype and model will improve the regulation and track of the temperatures and will certainly result in effective and efficient process of milk pasteurization by making the use of a solar parabolic collector.

1.1 Analysis and Design

The performance of plate type milk pasteurizer was analyzed in a commercial dairy plant having installed capacity of 1.0 lakh lit./day. The purpose of the analysis was to determine the regeneration efficiency and utility usage including steam, chilled water and electrical energy, in the milk pasteurization processing line. Theoretical and actual steam consumption was determined at rate of 155.72 kg/hour and 156.48 kg/hour, respectively. Chilled water utilization was found to be 25.11 m^3/hour which was 2.36 times than milk flow rate. Power consumption for milk pasteurization was found to be 16.09 kWh per hour. A storage unit for milk was developed in controlled temperatures enabling it for proper transport without any spoilage of milk that might take place during the transit. Necessary precautions were duly taken to prevent the breaking and spoilage of the components. The prototype was studied during different time slots considering different surrounding temperatures.

On the basis of experimental learnings, following components are used in the pasteurizing unit.

- Parabolic Trough as Collector

- Evacuated glass tube as receiver
- Cooling unit
- Storage tank

A parabolic trough collector looks similar to a large satellite trough, but has mirror-like reflectors and an absorber at the focal point. Parabolic trough collectors can attain temperatures above 100°C at the receiver end. It therefore makes it easy and possible to achieve the highest efficiencies for conversion of solar energy into electricity in the small-power capacity range. They are highly efficient at thermal energy absorption. Unlike the flat-plate type of solar collectors, evacuated glass-tube solar collectors are able to collect the sun's energy from multiple angles due to their 360° tubular construction. When the sun rays fall at a lower angle, it is nearly impossible for most flat-plate solar trough systems to trap the solar thermal energy. This is not the case with evacuated glass-tube solar collectors. They are constructed with a broader collector area to allow maximum utilization of the sun's energy, both during the day and for an extended period during the year. This means that solar thermal heating systems using evacuated glass-tube collectors work more efficiently in mid-morning as well as mid-afternoon. Comparatively, evacuated tube solar collectors require less space on the roof and the collectors are relatively easy to install due to their modular construction. Evacuated glass-tube solar thermal collectors are durable for a minimum of twenty years, with minimal maintenance.

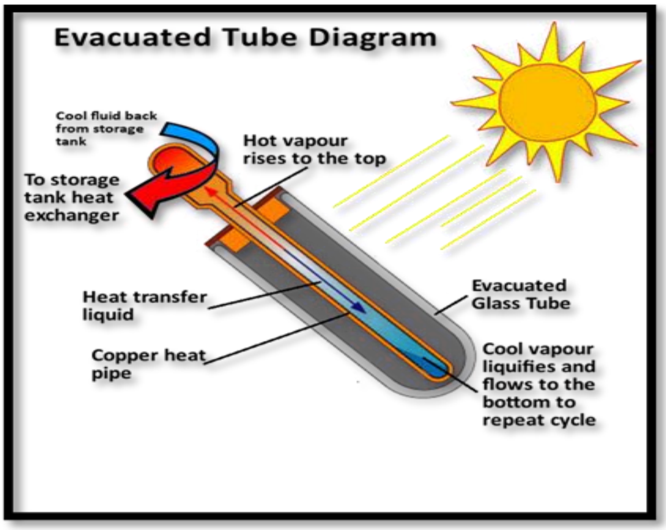

Figure -1: Schematic Diagram of Evacuated Tube

The inclusion of a cooling system is to transfer heat from a cold chamber that is at lower temperature than that of the surroundings. Heat is absorbed at a lower temperature and given out at a higher temperature as work is supplied at the compression unit. The refrigerant continuously flows within the cycle and changes its physical state. Compressors are positioned between the evaporator and the condenser. They can be installed in either single stage or multi stage configuration and can be connected to each other in parallel as well as series. The compressor helps in compressing the refrigerant and also removes the vapor that is produced by the evaporator and then finally delivers it at a required high pressure. The refrigerant vapor that reaches the compressor from the evaporator is of low pressure and low temperature. During the compression process, the temperature and pressure of the refrigerant rises.

1.2 Operating cycle

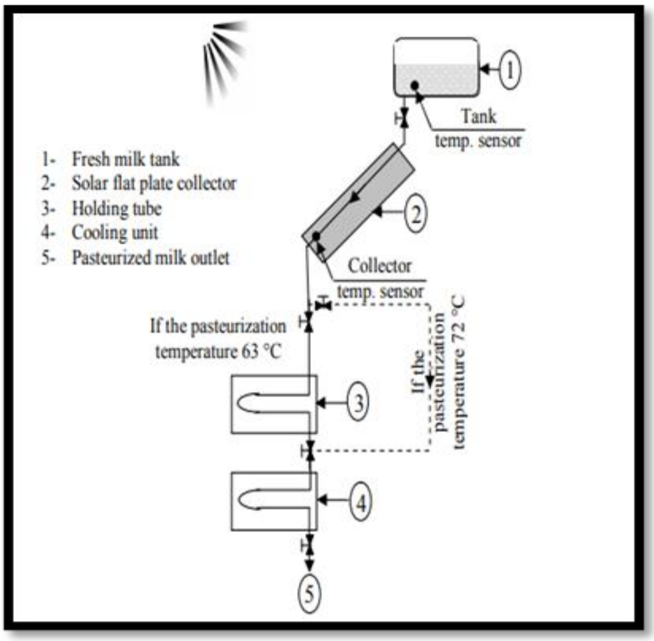

Figure -2: Operating cycle of Milk pasteurization

A parabolic trough reflector, shown schematically in above figure is an evacuated tube-focus collector concentrating solar energy onto a receiver located at the focal point of the trough. The trough structure must track the sun fully in order to reflect the ray into the receiving thermal unit. The receiver absorbs the radiant solar energy, converting it into thermal energy in the circulating milk. This thermal energy can then either be converted into electricity using an engine-generator coupled directly to the receiver, or it can be carried through pipes to a central power-conversion system. Based on the calculations at a given time, the angle is set at 91°. The parabola is designed and made of composite aluminum sheet metal which is then welded onto the frame structure. An evacuated glass tube is fitted at the focal point of the parabola. The glass tube has a black coating in order to increase the absorption capacity of the glass tube. The evacuated glass tube contains copper tubes passing through the entire length of the tube. The diameter of the copper tubes is 6mm and the length is 1.5m. When the solar beams fall on the parabola, it is reflected from the surface and the rays are incident on the focal point where the glass tube is fitted. This causes the glass tube to heat up. A vacuum is present between the glass tube and copper tubes. The principle of greenhouse effect is observed here thereby trapping the heat inside the glass tube which results into heating of the copper tubes. The milk then passes through these copper tubes which result in their heating to the required temperature. At the outlet of the parabola, the required temperature of 65°C is obtained.

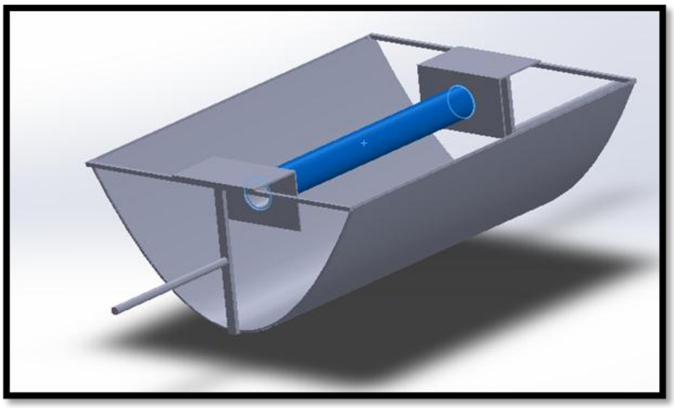

Figure -3: Reflector sheets with Evacuated Tube

The milk is then passed to the chiller unit. The refrigerant used in this study was R-134a. In the chiller unit the milk is first cooled to a lower temperature of 4-5°C. After chilling, it is then sent to the final storage unit where it is stored in a controlled atmosphere. The storage temperature is set between 25-30°C. From there, it can then be sent to the packing unit where it is packed and then transported to the various locations.

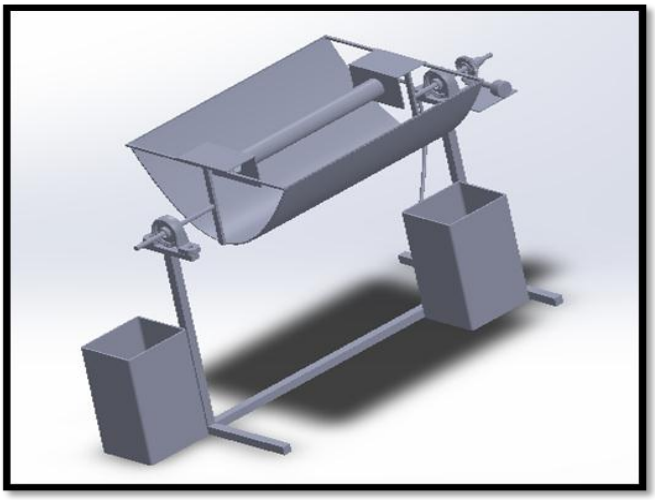

Figure -4: Milk pasteurization unit assembly

2. EXPERIMENTAL CALCULATIONS

The confirmatory test was carried on three different dates with six different intervals. The pasteurized samples of milk that were observed were slightly lighter in color. Following were the noted observations.

Table -1: Temperatures recorded on 3 dates with 6 intervals

Date	Atm. Temp. (°C)	Water Temp. (°C)	Milk Temperature (°C)					
			11 am	11:30 Am	12 pm	12:30 pm	1 pm	2 pm
11 Mar	36	35	38	46.8	54.7	64.2	61.6	40
15 Mar	35	34	-	43.5	53.6	62.3	56.4	43
21 Mar	37	35	-	-	55.3	66.7	60.1	45

The observed values were then statistically plot and analyzed. On the horizontal axis, the independent variable of time was taken whereas on the vertical axis dependent variable of temperature was taken.

Table -2: Polynomial Regression of Temp. vs Time (Day 1)

Temp. (°C)	Constant	Linear	Quadratic	Cubic	R^2
Atm.	36.72	0.232	-0.002	0.00012	97.23%
Water	35.66	0.535	-0.005	0.00004	95.51%
Milk	38.21	0.667	-0.003	0.00005	98.32%

Table -3: Polynomial Regression of Temp. vs Time (Day 2)

Temp. (°C)	Constant	Linear	Quadratic	Cubic	R^2
Atm.	35.16	0.152	-0.0021	0.00014	93.56%
Water	34.19	0.364	-0.006	0.00024	96.42%
Milk	40.61	0.142	-0.005	0.00007	97.54%

Table -4: Polynomial Regression of Temp. vs Time (Day 3)

Temp. (°C)	Constant	Linear	Quadratic	Cubic	R^2
Atm.	37.33	0.366	-0.001	0.00044	95.46%
Water	35.26	0.515	-0.0051	0.00004	97.72%
Milk	50.61	0.257	-0.003	0.00009	99.21%

- Flow Rate through evacuated tubes:

Flow rate $=\frac{Distance}{Time}$

$=\frac{Total\ length}{Time}$

$=\frac{h}{t}$

$=\frac{1200}{3600}$

$= 0.3333 \sim 0.33 \times 10^{-3}$m/s

d=6mm

v=0.33 mm/s~ 0.33 x 10^{-3}m/s

Q=A.V

$=\frac{\pi}{4}(d)^2 \times 0.33$

$=\frac{\pi}{4}(6)^2 \times 0.33$

So, Q=9.325mm^2/s

Q=10×10^{-9}m^2/s

- Heating Capacity:

$=(v * \rho) * C_p * (Ti - To)$

V=$10 * 10^{-9}$ m^2/s

$\rho = 1000$ kg/m^3

Cp =4.19 kJ/kg k

$=(10 * 10^{-9} * 1000) * 4.1970 * (65 - 25)$

$=1.678*10^{-3} kw$

- Chilling Capacity:

$Q_c = (v * \rho) * Cp * (65 - 4)$

V=$10 * 10^{-9}$ m^2/s $\rho = 1000$ kg/m^3

Cp =4.19 kJ/kg k

Qc=$10 * 10^{-9} * 1000 * 4.19 * 61$

Qc=$2555900 * 10^{-9}$

$=2.556*10^{-3} kw.$

Fig -5: Actual working unit of Milk Pasteurizer

3. CONCLUSIONS

The tests carried out during three different days in Pune, Maharashtra successfully showed the pasteurization of milk at the expected temperatures. This was a direct method espoused for obtaining pasteurized milk from solar energy. The results delineate that there is still immense scope in the utility of solar power for crucial domestic household processes like pasteurization. The obtained milk was free from contaminants and other microbes. This pasteurization unit could be set up by the locals easily in the proximity of their homes and in an open area, where they will be able to save upfront costs on fuel or other items such as charcoal and firewood. The temperatures were recorded using a digital thermometer and the chances of human errors in recording the temperatures were found to be null void. The experimented set up was studied under all risk factors, and the unit proved to be easy to use with almost zero risk. Care should be taken while handling the hot evacuated tubes and it is recommended to keep the unit at a safer distance from children. The milk pasteurizer showed the required temperatures in near about two hours without any gap in the heating process.

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