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DEVELOPMENT AND PERFORMANCE EVALUTION OF SOLAR ASSISTED MILK PASTEURIZER BY USING VACUUM TUBE COLLECTOR

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Raw Milk is considered as a tremendous medium for contagious growth of bacteria's and other pathogens which soon get accelerate when stored at ambient temperature. Pakistan is at 3rd place in worldwide milk production. Here about 41.6 million ton of milk is being produced annually from which only 5% get processed and pasteurized hardly and remaining proportion of milk is handled by milk man under non-hygienic conditions which causes diseases. Dairy processing is a rapid growing business but high operational cost is a serious problem. The solar energy in combination with vacuum tube collector having 200 litres capacity and 2.088m² collector area is an efficient way of pasteurizing the milk. Steam is used to pasteurize the milk stored in stainless steel tanks. Milk is heated up-to 63°C temperature in 30 minutes, then cooled down to 30°C through heat exchanger by using natural tap water. Furthermore, milk is cooled down to 4°C in the chiller within 90 minutes which is powered by 2kW Photovoltaic system. Rotary compressor was used in the chiller which reduces shunt load. Torque load is zero by applying invertor technology in chiller. Efficiency of the unit was achieved up-to 69%. The payback period of this unit is 3.8years and processing cost occur 1.8 PKR per litre. This research study is conducted to prolong the shelf life of milk and results as the most excellent and economical way of preserving milk through this solar energy resource technique.
Keywords: Milk pasteurization, bacteria, alkaline phosphate, solar energy, inverter technology.

INTRODUCTION

Man has always used the sun rays for his energy requirement. With the increasing environmental factor every day, new alternate system is being investigated. Now a day solar energy is becoming very popular (Duff and Hodgson, 2005). For better utilization of solar energy two components namely collector and storage unit are required. The collector absorbs the sun light that falls on the collector and sends it to other forms like electricity, heat etc. (Virgiliu *et al.*, 2007). The storage unit is essential for the collection of energy because during cloudy days, the energy generated is small. The storage unit can store energy during the periods of maximum radiation (Kablan, 2004).
Solar milk pasteurization is the process of killing bacteria from milk and making it free of micro-organisms by using the sun rays (Safapour and Metcalf, 1998). The sun rays are utilized to produce the steam with the help of solar vacuum tube collector which produces hot water at very high temperature (Wayua *et al.,* 2012).
Milk is a natural liquid diet, and this is one of our utmost nutritionally complete diets. Milk holds microbes it generates conditions when it improperly handles microbes can proliferate Antibiotic deposits in milk due to widely use of antibiotics in food producing animals, supposed reason for the both dairy manufacturing and customers. To kill that bacteria's or microbes which develop slowly or create pores, suitable temperature and time must be applied (Zorraquino *et al*., 2008).
Pakistan is the third most milk producing country in the world (41.6 million tons annually) whereas larger proportions of producers are small scale farmers. Only 5% of this milk is processed while other handled by milkman which is mostly non-hygienic health risks related (FAO, 2011). Farming community do not get proper price for their milk due to the non-availability of processing facilities at farm level. Price of Nestle packed milk is 110 Rs/litre which is not easily available because non-pasteurized local milk is easily available at about 70 Rs/litre.
In Pakistan 96 % of the milk production came from cows and buffalos. The remaining of 4% is jointly produced by sheeps, goats and camels, which is rarely vended as such, somewhat utilized homely or mixed with buffalo and cow milk.

Table1. National livestock population of Pakistan.

Kind	Population (Millions)
Cow	41.90
Buffalo	36.80
Sheep	31.50
Goat	67.80
Camel	2.00
Total	180.00

Source: National livestock Census 2006 & Economic Survey of Pakistan 2013-14.

The "US Centres for Disease Control (CDC)" declares "incorrectly controlled fresh milk is liable for hospitalizations practically 3 times more than any other food-borne disease outbreak, making it one of the world's most dangerous food items".

If milk is not properly handled or pasteurized then it causes diseases like brucellosis, diphtheria, tuberculosis, scarlet fever, and Q-fever. To avoid these diseases, destroy harmful bacteria's like Campylobacter, Listeria, Yersinia, Staphylococcus aureus, Salmonella, and Escherichia coli (Villamiel *et al.*, 1997). So that pasteurization of milk is important to make the milk free from food borne diseases by using low cost energy which does not affect to environment. Maximum number of the germs in fresh milk came from a healthy animal are whichever inoffensive or useful but quick deviations in the health of an animal, or the milk man or impurities from polluted water, dust, dung, flies, air cuts and wounds hack make fresh milk potentially unsafe (Berney *et al.*, 2006). Fresh milk holds alkaline phosphate (ALP) is an enzyme naturally exist in fresh milk which is liable for intra-abdominal microbial infection while milk used for a drinking purpose (Fenoll *et al*., 2002).

There are four types of milk pasteurization e.g., low temperature holding (LTH), high-temperature, short-time (HTST), ultra-heat-treating (UHT) and batch pasteurization (Zahira *et al.*, 2009) which are described here as below;

In LTH pasteurization, milk is stored in a tank. Steam is applied at the outer surface of the tank through insulated pipes. In this type milk is heated up-to 63°C for 30 mints (Lucentini *et al.*, 2012).

In HTST pasteurization, milk is flowed under certain pressure between metallic plates or through pipelines. Heat is applied on the outer periphery by hot water to rise milk temperature. It is heated up to 72°C (161.6°F) for 15 seconds (Razzak *et al.*, 1985).

In UHT pasteurization, milk is sprayed into chamber filled with high-temp steam under pressure. Now milk is heated up-to 140°C (284°F) for 4 seconds. After heating cooled it suddenly in a vacuum chamber and then packed in a pre-sterilized sealed container. Now this milk is store for several months without refrigeration (Pandey and Gupta, 2004).

In Batch pasteurization, milk is heated up-to 63°C (145.4°F) in a closed large box and hold at that temperature for half an hour. In batch type processing, the milk must be agitated persistently to make sure that each drop of milk is heated equally.

The objective of the study was to to design the energy efficient solar milk pasteurizer, develop the 200 litre batch type milk pasteurizing technology for on farm processing and analyze the performance and economics at local conditions.

MATERIALS AND METHODS

This study was carried out to develop and test the performance of the environmental friendly designed solar assisted pasteurizer for the pasteurization of milk to enhance its shelf life and made it marketable product for dairy farmers. Solar irradiance, ambient temperature, hot water temperature, milk temperature, agitation, hot water flow rate, time period, heat energy added to the milk and remove, energy obtained by the vacuum tube collector, collector area of vacuum tubes, heat energy extracted (cooling load) from milk were the key parameters for this research study evaluation process. The whole unit of milk pasteurizer had been developed and fabricated by locally available food graded material SS-304 in the workshop of Farm Machinery & Power, University of Agriculture Faisalabad.

***Vacuum tube collector*:** Vacuum tube collector was designed taking into consideration of local topography (Lat, Long), intensity of solar radiations available and environmental conditions data by taking all these parameters designed was drawn in AutoCAD. Vacuum tube collector with heat pipes were selected to pasteurizer the milk. The No. of tubes was 20 and each glass tube has size of Ø58mm x 1800mm. The glass vacuum tubes material were borosilicate glass and structure were concentric dual tube geometer. The outer and inner diameters of tubes were Ø58mm ± 0.7mm and Ø47mm ± 0.7mm respectively. The glass tube length was 1800mm ± 5mm and vacuum was $P<5x10^{-3}$ Pa. The average heat loss coefficient from tubes was 0.8W/m² °C. For the storage of hot water stainless steel tank with 200 litre storage capacity were installed. The temperature from vacuum tube collector achieved up to 100°C.

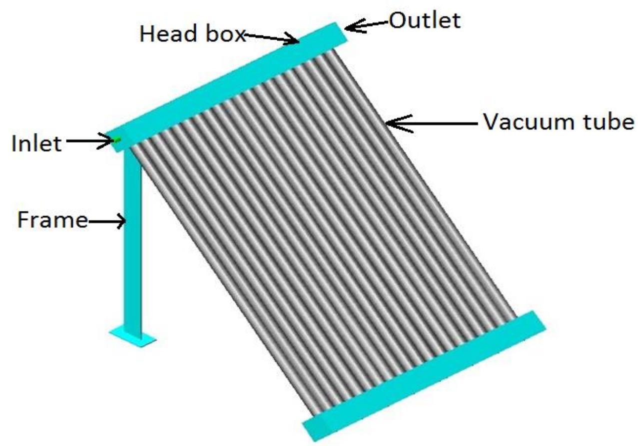

Figure 1. Isometric view of Vacuum Tube Collector (Auto CAD)

***Pasteurizer*:** Pasteurizer is the main unit for the pasteurization of milk. Milk is heated up-to 63°C for 30 mints. Temperatures must be controlled to avoid substantial changes in the properties (particularly its color and taste) of the milk through thermocouple which was installed inside the pasteurizer; the display screen at the top of pasteurizer was showing the temperature variation in degree Celsius. Display screen powered by PV panel source solar electric supply through a control electric unit of hybrid solar system. The electric motor with stirrer was also installed at the top of pasteurizer unit to stirrer milk continuously. A helix coil of 25 mm² was installed in side of outer and inner tank. The hot water which was heated up to 90 to 100°C through vacuum tube collector was passed through the helix stainless steel coil to raise the temperature of milk to make it bacteria free. The hot water (steam) was entered inside the helix coil from the lower side of inlet pipe and drained from the upper end of the helix pipe. The centrifugal electric pump was used with three different operating speeds to flow the water inside helix pipe. Hot water energy was added to the milk to pasteurize it.Pasteurizer tank having capacity of 100 litres, Diameter 558.8mm and Length 432mm;

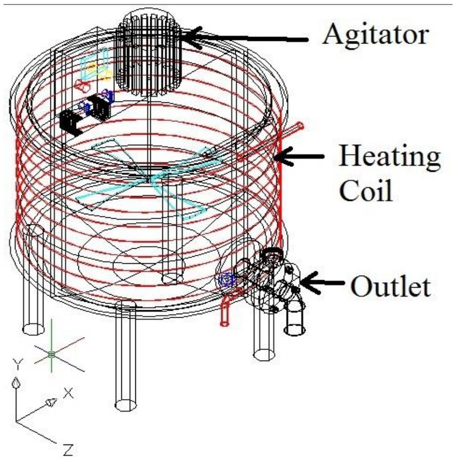

Figure 2. Isometric view of pasteurizer (AutoCAD)

Figure 3. Heating Pasteurizer unit in real

Solar PV panels**:** Solar PV Panels were installed to provide the renewable electric power supply to function the chiller, agitator of pasteurizer and centrifugal type heat pump. Poly type 8 PV panels were installed each having 250W output DC power. Total 2 kW off grid systems were installed with batteries as a backup.

Figure 4. Solar PV panels of 2kW.

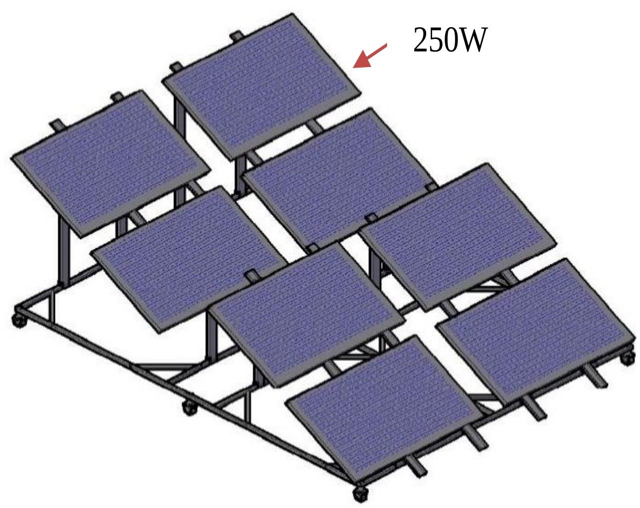

Figure 5. Isometric view of PV panels (Auto CAD).

Chiller**:** Chiller was used to remove heat from milk via "a vapor-compression or absorption refrigeration cycle". In the design &chillers selection parameters includes performance, efficiency, maintenance, and product life cycle environmental impact. Rotary compressor with inverter kit was installed. Torque load was zero by using this inverter technology. Chiller main function was to cool down the milk to 4°C.

Table 2. The detail specifications on the chiller.

Description	Values
Chiller tank capacity	200 litres
Observational hole	Ø220mm
Dimensions of ta	970mm * 770mm * 550mm
Frame dimensions	510mm * 1580mm
Refrigerant	R-410A
Load required	1 kW
COP	2.83
Agitator motor	186 W
Material	Stainless steel (SS-304)
Control unit	to operate whole chiller (Plastic)
Display screen	LEB

Milk after pasteurization at 63°C cool down to 30 to 32°C by applied the natural tap water with in the same 25 mm² coil of pasteurizer. Milk having temperature 30°C transferred into the chiller to cool down it 4°C within 90mints. A scale was also display at the wall of chiller to note or measure the quantity of milk in liters. Observational hole of 220mm diameter was installed at the right corner of the chiller with top cover gate. Milk drain hole was provided at the right bottom side of the tank sheet. An out let pipe having flanged with handle to open and close the out let pipe to drain out the milk with lock.

Figure 6. Milk chiller.

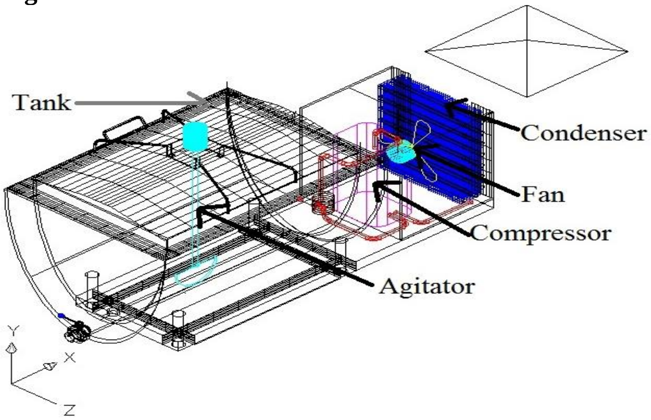

Figure 7. Isometric 2D view of chiller (AutoCAD).

Agitator**:** Agitator is a mechanical device which drives with electric motor to stirrer or mix the milk. In this research agitator was used in pasteurizer as well as in chiller to stirrer it. In pasteurizer agitator had 18 rpm by which milk warm in less time and each drop of milk received equal amount of heat. After pasteurization of milk at 63°C agitator helped to cool down the milk rapidly. While in chiller agitator had 30rpm by which each drop of milk cool down equally.

Control unit cabinet**:** Control unit cabinet was designed to put all electronic devices inside it. Solar off grid system was installed inside this cabinet through copper wires. All electrical devices like data logger, inverter, charge controller and dry gel batteries were installed in separate sections. This cabinet had height of 1500mm, width 900mm and inside 600mm long. It had 4 sections three were equally spaced 400mm and lower one section had 300mm height. Upper section were used for inverter, data logger and charge controller, middle 2 sections were used for batteries while the lower section was used for wires and miscellaneous. Steel sheet of 16 gauge (1.5mm) was used as a material with powder coating. A glass door with lock was fixed with the cabinet.

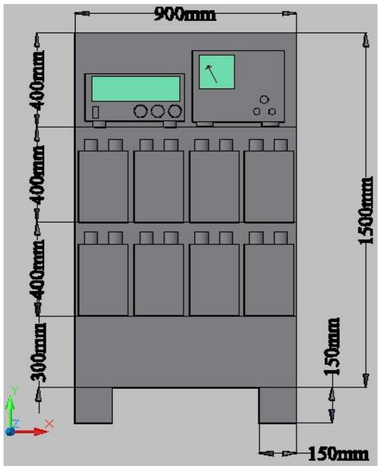

Figure 8. Control unit Cabinet (Auto CAD).

Figure 9. Control unit cabinet.

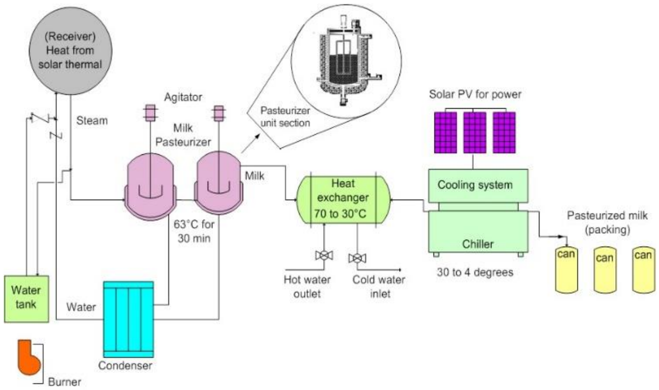

Figure 10. Schematic flow diagram of whole processes during pasteurization of milk.

***Collector area*:** The vacuum tube collector area can be calculated by using following formula (Vendan *et al.*, 2012).

$$A = \frac{m.C_p.\Delta t}{I_t.\tau.\alpha.\Delta T} \quad (1)$$

Where, A = Area of receiver tube exposed to radiations (m²) m = Mass of water (kg), C_p = Specific heat capacity of receiver tube (kJ/kg.°K), ΔT = Change in temperature (°K) I_t = Solar radiation (W/m²), τ = Transmission coefficient α = Absorption coefficient, Δt = Time (sec)

***Number of tubes*:** The determination of number of tubes depends on the size of each tube available commercially. It is calculated as

$$N = \frac{\mathbf{Collectorarearequired}}{\mathbf{Projectedareaofstandardtube}} \quad (2)$$

***Heating load*:** The following formula was used to calculate the amount of heat was required to rise the milk temperature up to 63°C or bacteria free level

$$Q_m = m.C_p.\frac{\Delta T}{t} \quad (3)$$

Where, Q_m= Heat Load (Heat required for milk, (kJ/s), m = Mass of milk (kg), Specific density of milk= 1033kg/m³ C_p = Specific heat of milk ($\frac{kJ}{kg.°K}$), C_p= 3.93$\frac{kJ}{kg.°K}$, ΔT = Change in temp. (°K), t = Time (sec)

***Cooling load*:** To calculate the cooling load (power) required; means how much amount of heat energy was removed from the system to decrease the temperature of milk for pasteurization. The heat removed in two steps. In the first step, heat was removed through exchanger device where water used as cooling agent while in second step, it will be removed (cool down at 4°C) with chiller by using PV panels as power source. It should be in (-ve), the following formula's was used

$$Q_c = m.C_p.(\frac{\Delta T}{t}) \quad (4)$$

***Power (total load) required*:** Heat (energy) divided by time power (total load) was calculated

$$\frac{q}{t} = \frac{m}{t}.cp.\Delta t \quad (5)$$

$$\text{kW} = (\frac{kg}{s}).(\frac{kj}{kg.°k}).(°k)$$

Total incoming energy:

$$G = \frac{I_t.A_c}{1000}(\text{kW}) \quad (6)$$

Where, G= Total incoming energy (kW), I_t = Solar Irradiance (W/m²), A_c= Tube collector area (m²)

Efficiency of the System:

$$\eta = \frac{Q}{G}.100 \quad (7)$$

Where, Q = Total heat Load (kW), G = Total incoming energy (kW)

Annual mean Solar Radiation in Faisalabad is 5.5-5.8 kWh/m².

***Total Power is required from PV system for chiller*:** Operating time to cool down milk is 2 hours standard by WHO

$$Total\ load = P.t \quad (8)$$

$$= \text{Watt.hr}$$

***How big PV system has to install*:** For PV system we calculate peak sun shine hours; as we know sunshine is less at morning and evening but more at noon. Also days are longer in summer but shorter in winter. Another considerable thing is rainy season and fog. In order to run out PV System consideration of all conditions we consider peak sunshine hours as 5hours per day.

$$PVPanels\ requirement = \frac{TotalLoad(W.hrs)}{Sunshine\ (hrs)} \quad (9)$$

RESULTS AND DISCUSSIONS

This solar assisted milk pasteurizer unit was tested at Latitude 31.4371°N and Longitude 73.0699°E; and research was conducted to evaluate the performance of solar milk pasteurizer by using vacuum tube collector as solar water heaters. The data were collected every day with help of data logger. The research was conducted during month of August and September 2016.The collected data were statistically analyzed. The relevant tables and the findings of analyzed data have been presented in below graphs.

***Milk temperature*:** Milk temperature was increased as the water temperature increased continuously. In the start of experiment temperature of milk increased slowly while with the passage of time the temperature was increased rapidly to kill the harmful bacteria's, 63°C temperature was achieved in 30 minutes.

After this pasteurization of milk or water in the pasteurizer the temperature was 63°C. Now milk was cooled down to 30°C by passing the tap water from the same coil of pasteurizer tank, so according to the law of thermodynamics milk temperature was equalized to the tap water temperature 30°C in 10 minutes. This process was achieved by applying hydraulic water, fluid flows from top to bottom, no extra electric power required.

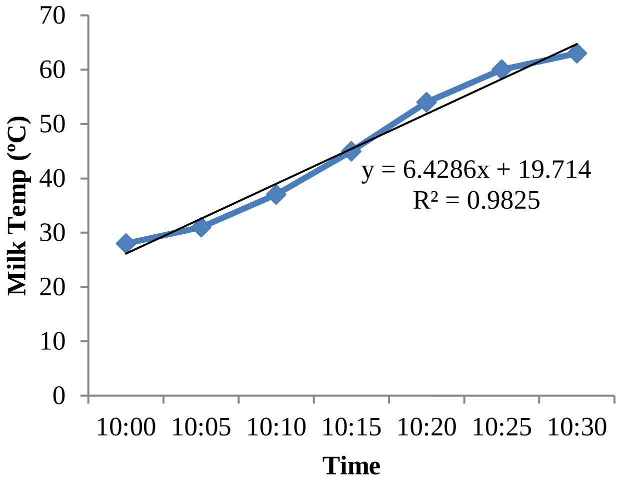

Figure 11. Graph shown the temperature raise with respect to time.

***Heating load*: The heat load is that amount of heat energy which was required to the milk for pasteurization. We had pasteurizer tank with capacity of 100 liters, this was converted in to mass by multiplication of density of milk (1.03 kg/liters) with volume of milk 100 liters. While the specific heat of milk is 3.93 $\frac{kJ}{kg.°K}$ temperature of milk is raised from 28 to 63°C for this data; the amount of heat is added to the system is calculated by following equation;

Q_m= 7.64 kJ/s (amount of heat added)

***Cooling load*: Cooling load is that amount of heat which is extracted from the system. Heat is extracted from the system in two stages. In the 1st stage the heat is extracted from the system with the help of condensation principle. The tap water is passed from the same coil of 25 mm² area in the pasteurizer to extract the heat from the system. By this mechanism milk cool down from 63 Celsius to 30 Celsius.

Q_c = 12969 kJ (amount of heat extracted)

= 7.205 kJ/s

2nd Stage:

While in the second stage, milk is further cooled down to 4°C to chill it in the chiller. Chiller was operated with AC supply source provided from solar PV panels through controlled off-grid system. Chiller was designed for the 200 liters' capacity of milk to chill down at 4°C.

Q_c = 20436 kJ

= 20436/7200 = 2.83 kW

Power is calculated by the given below formula;

$$\text{Input Power} = \frac{Q'}{CoP}$$

Where, Q' = Refrigeration (kW), Input Power = Electricity consumed (kW), COP = 2.83

Firstly, designed chiller with conventional compressor consumed high ampere and took 3.2kW torque load which was unable to run with 2kW PV power source. To solve this problem chiller compressor was replaced with rotary compressor, that resulted the load consumption reduced. Torque load vanished through introducing inverter (kit) technology in chiller.

The chiller equipped with conventional compressor, which utilized torque load 3400 W in running and then it consumed approximately 1600 W during the course of cooling milk at 4°C in 70 minutes as shown in Figure 12 & 13.

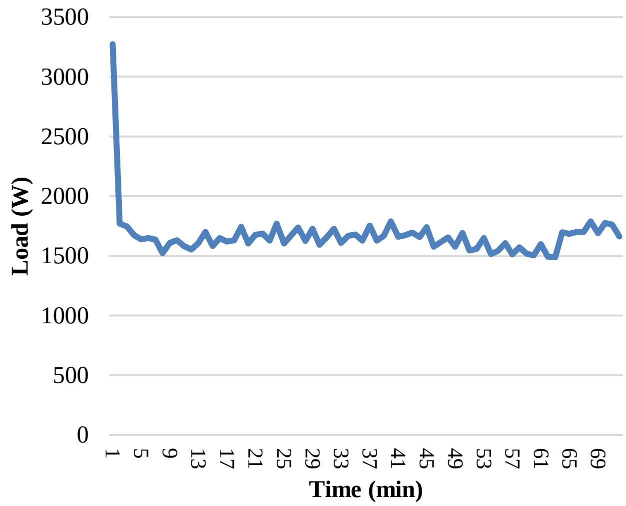

Figure 12. Graph b/w load vs time conventional compressor of chilling system.

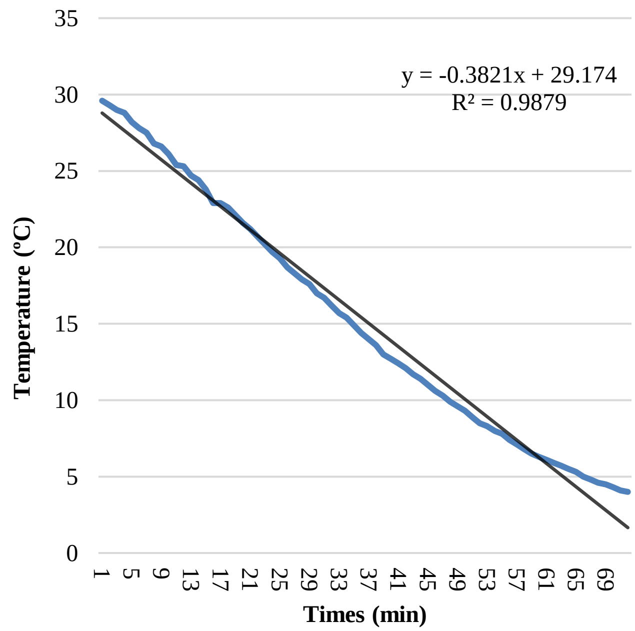

Figure 13. Temperature fall of milk in chiller with conventional compressor.

The chiller was tested by replacing the conventional compressor with rotary compressor in addition which was equipped with capacitor, in this test it utilized approximately 1400 W to chill the milk at 4°C in 70 minutes as shown in Figure 14 & 15.

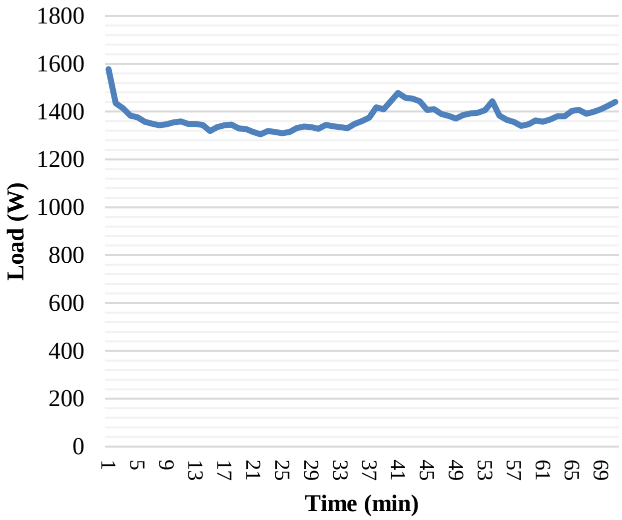

Figure 14. Graph b/w load vs time by using efficient rotary compressor with capacitor.

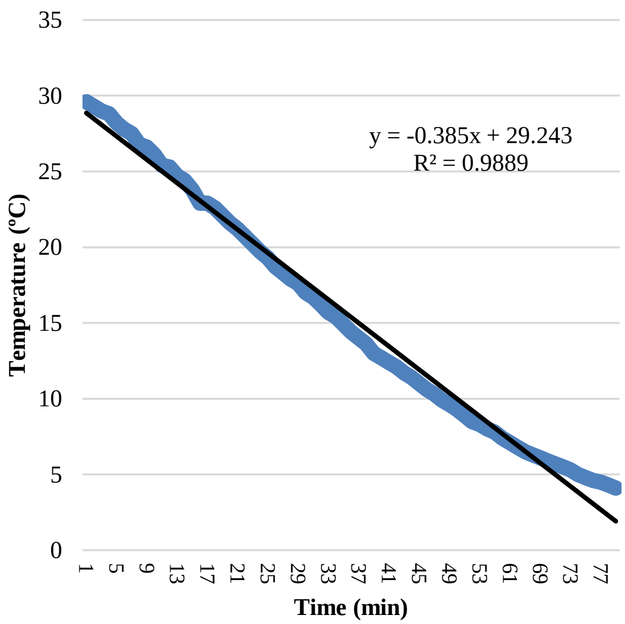

Figure 15. Temperature fall of milk in chiller with rotary compressor.

Figure 16 & 17 describes the chiller load utilization. In this test, rotary compressor installed with DC inverter which consumed less than 1000 W to cool down the full 200 litres capacity of chiller from 28 to 4°C in 90 minutes with zero torque load.

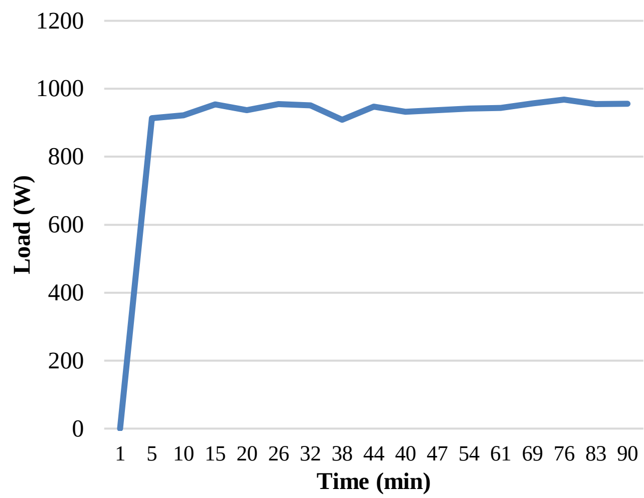

Figure 16. Graph b/w load vs time by using rotary compressor with inverter kit.

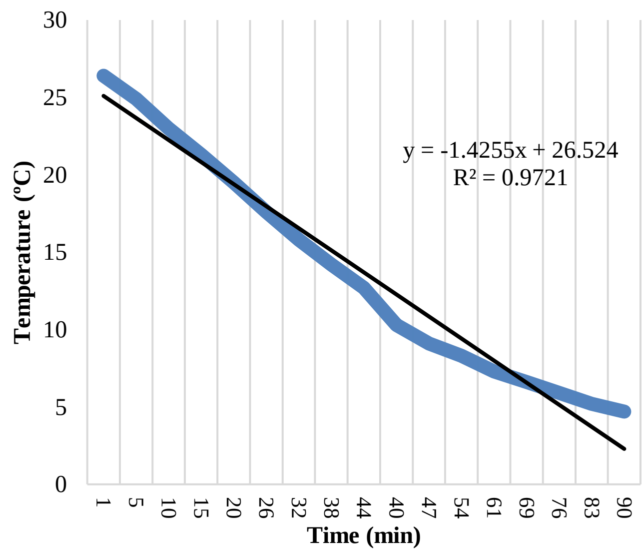

Figure 17. Temperature fall of milk in chiller with rotary compressor with inverter kit.

***Payback period*:** The payback for the solar assisted milk pasteurizer was calculated taking in consideration of alternative fuel (electricity) saving (McPeak, 2003) defined as in Eq 10;

$$\text{PayBackPeriod(annualy)} = \frac{\text{Capitalcostofpasteurizer}}{\text{Costsavingperyear}} \quad (10)$$

The capital cost of the pasteurizer is 0.5 million rupees. The running cost of this solar assisted pasteurizer is very minimum (zero) due to solar operated. If it was alternatively operated on electricity (WAPDA) then it's consume 19.7 kWh in a day, 1 kwh unit price is 18 rupees including Taxes & misc, 19.7x18=354.6rupees per day and 129,429 rupees annually cost will occur, payback period = 500000/129429= 3.8 year. Average life of the pasteurizer unit is 10 years. After 3.8 year the initial cost of the pasteurizer unit will be recovered, farmers will use this pasteurizer technology free of cost for the remaining years.

***Conclusion*:** This method of pasteurization of milk using solar energy is better for dairy farmers and dairy industries in Pakistan. This research study of solar assisted milk pasteurization has revealed that the system worked more efficient with respect to any conventional system. Chiller equipped with conventional compressor took torque load of 3400W in starting and consumed 1600 W which was impossible to run it on 2 kW PV power, while rotary compressor installed with inverter kit consumed less power under 1000W with no torque load. It has benefits like environmental friendly, no pollution because there is no any combustion involved, effective utilization of solar energy as system worked on 69% efficiency, decentralized application for on-farm processing, processing cost is 1.8 PKR/litre and pay back is 3.8 year.

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