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Design, Construction and Implementation of a Solar Parabolic Dish Milk Pasteurizer in Yola, Nigeria

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Abstract: *A suitable solar parabolic dish milk pasteurizer was designed, constructed and implemented in Yola Nigeria, using locally available materials. A parabolic dish of 1.8 m in diameter was used as a collector. The system was tested for milk pasteurization under Yola climatic conditions on clear daysbetween the hours of 11:00 am and 3:00 pm local time. Three types of pasteurization: low-heat pasteurization (LH), high-heat pasteurization (HTST) and high-heat short time pasteurization (HHST) were performed at their corresponding temperatures. The system was designed with the capacity to pasteurize 6 liters of milk at once, pasteurization of large quantity of milk can be done in batches. From the test results the optical efficiency of the collector was found to be 0.28 with the heat loss factor of 7.12 $WK^{-1} m^{-2}$and the system efficiency was found to be 56 %. The availability of cow milk and high rate of milk consumption in Yola, makes the constructed solar milk pasteurizer an ideal system of complementing or a good replacement for conventional energy resources used for milk pasteurization in Yola Nigeria*.

Keywords: *Pasteurization, Solar Radiation, Parabolic dish, Micro-organisms*

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I. INTRODUCTION

Milk and its products are fundamental in human nutrition. It can be used as an important part of diet throughout life. The milk is a perishable foodstuff because it is an excellent medium for the growth of micro-organisms which cause spoilage. Heating milk to a specific temperature for a specific period of time leads to destruction of harmful micro-organisms. This process is called pasteurization [1]. Energy is needed for doing the previous process, even at a very modest scale of operations. However, energy from conventional sources is becoming increasingly expensive [2]. Capturing the sun's energy may be a logical solution to solve the energy problem caused by scarce fuels. It is free and has no negative impact on the environment [3].

Most of the bacteria in fresh milk from a healthy animal are either harmless or beneficial but rapid changes in the health of an animal, or the milk handler, or contaminants from polluted water, dirt, manure, vermin, and wounds cab make raw milk potentially dangerous [4]. Raw milk contains Alkaline Phosphate (ALP), an enzyme naturally present in raw milk which is responsible for intra-abdominal bacterial infection when milk use for drinking purposes [5,6&7].

In areas where sunlight is plentiful the use of sunshine to cook and pasteurize milk and contaminated water require our more concentration on industrial level to develop cheap and pollution free technology [8]. Among available alternatives solar pasteurization is a cheap, energy-efficient, robust and adoptable technique in sun-rich areas [9]. Research has shown that Yola has an availability of solar radiation for the smooth operation of solar dependent devices [10]. With the availability of cow milk and high rate of milk consumption in Yola, the need for milk pasteurization using solar energy was achieved. Pollution from fossil fuels and firewood can only be minimized if majority of the populace use cleaner and environmentally friendly sources of energy like solar and wind [11].

Unpasteurized milk and milk products have the potential to transmit pathogenic (disease- causing) organisms to humans. The nutritional components that make milk and milk products an important part of the human diet also support the growth of the organisms. Drinking raw milk causes foodborne illness, and dairy producers selling or giving raw milk to friends and relatives are putting them at risk. Fortunately, the threat of diseases involving milk and milk products has been greatly reduced over the decades due to pasteurization which render milk safe for human consumption [4]. During pasteurization, *Mycobacterium tuberculosis, Coxiellaburnettii,Brucellaabortisetc,*are destroyed and the physical properties of the milk are preserved (Fellows, 2017). Three types of pasteurization are possible:

i. Low temperature pasteurization (LH) which is done during 30 min at 63°C,
ii. High temperature short-time pasteurization (HTST), done during 15s at 72°C,
iii. Flash pasteurization or high heat short-time (HHST), which is done at 89°C for 1s

Using solar energy for milk pasteurization is a means of providing safe milk for human consumption without polluting the environment. Economically it reduces the use of conventional energy resources. Pasteurization of milk using solar energy helps to preserve more of the natural nutrients of the milk and its gustatory quality by the application of steady heat.This work will mitigate the menace global warming and climate change by curtailing deforestation, reduce the use conventional energy sources by utilizing solar energy for milk pasteurization in Yola.

Aidan (2014) constructed and evaluated a parabolic solar dish cooker under Yola climatic conditions using the international standard procedures for the evaluation of solar parabolic cookers. The optical efficiency of the collector has been found to be about 17.86%, the overall heat loss coefficient of 8.896 WK^{-1} m^{-2} and the adjusted cooking power that measures its performance has been found to be 37.43 W. Aidan (2014) concluded that the parabolic solar dish collector cooker can be used by families for cooking in Yola to minimize the purchase of other cooking fuels for at least cooking the afternoon meals [11].

Franco *et al*. (2008) designed of a system for pasteurizing goat milk as a part of a process for artisan elaboration of cheese. The system consists in a Fresnel type concentrator used for cooking large amounts of food with a vaporizer located in the focus. The steam bubbles into the isolated container where the milk was cooked by a double boiler. When the desired temperature was reached, the steam flow was closed and the milk remains in this condition for 30 min into the closed container [12].

II. THEORY AND METHODS

2.1 Parabolic dish collector

Parabolic dish solar concentrator makes use of direct solar radiation for heating at its focus [11]. The measure of the concentration of the radiation flux is described in terms of the optical concentration C_o given by:

$$C_0 = \frac{I_r}{I_0} \qquad (1)$$

whereI_r solar intensity at the receiver and $I_O$is the solar intensity at the collector. Concentration ratio,C, can also be determined in terms of the aperture aerial dimension of the parabolic collector$A_a$and the receiver surface areaA_r; it is usually referred to as the geometric concentration ratio C given by:

$$C = \frac{A_a}{A_r} \qquad (2)$$

The focal height *f* with respect to the vertex of the solar parabolic dish collector, the height of the dish *h* and the diameter of the dish *D* are related by:

$$f = \frac{D^2}{16h} \qquad (3)$$

where: f is the focal length of the dish, *D* is the aperture diameter, *h* is the depth of the dish.

2.2 Fabrication Technique

The construction of the parabolic dish solar milk pasteurizer was carried out in three steps

i. Paraboloid construction
ii. Receiver construction
iii. Design of the pasteurizing device

The solar collector was made from a parabolic dish of a 1.8m aperture width, a depth of 0.28m and a focal length of 0.72m. The relationship between the depth and the aperture width asindicated in equation (3) is used to calculate the focal point where the absorber was placed.Thus, using the value of *D* and *h*, *f* = 0.72 *m.*
The reflecting material used as a reflector for the paraboloid is a plane mirror of 3 mm in thickness. This have the good strength and reflectivity. The whole reflected rays converge at the focal point of the dish, and absorbed by a receiver painted black and supported vertically.
The receiver was constructed cylindrical in shape with aluminum sheet, with diameter of 0.215 m and height of 0.3 m. The volume of the receiver (vaporizer) was calculated using equations (5).

$$\rho_w = \frac{m_w}{V_c} \qquad (4)$$

where; $\rho_w =$ density of water, kg/m^3

$m_w =$ mass of water, kg

V_c = volume of cylinder, m^3

Since,

$$V_c = \frac{\pi}{4} d^2{}_c \times h_c \qquad (5)$$

where; d_c = diameter of cylinder, m

h_c = height of cylinder,

The pasteurizing unit consists of three concentric cylinders. The innermost cylinder contains the milk that was pasteurized. The second cylinder act as steam container for heating of milk in the innermost cylinder. The outer cylinder was covered with insulation. The milk in the innermost container was directly heated by this steam. The milk container and steam container were constructed cylindrical in shape, made ofaluminum sheet and iron sheet respectively, and sawdust was used as insulation around the water jacket toprevent heat loss from cylinder. The dimensions of the cylinders were calculated from equations (4) and (5). The pasteurization device was design to process 6 liters at once using the steam produce by the concentrator. The recipient stand on iron base. Both elements make the handling and control of the system easy.

Table 1. Pasteurizing Device Specifications

Cylinder	Volume (m^3)
Milk Container	6.1x10^{-3}
Water Container (steam container)	15.0x10^{-3}
Outer Cylinder	29.0x10^{-3}

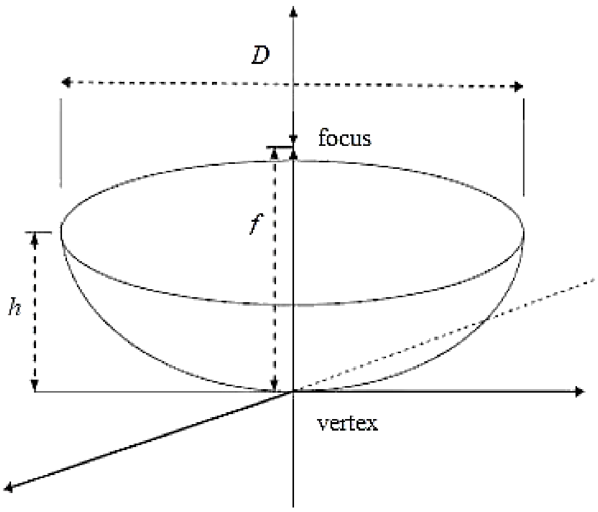


Figure 1. Schematic diagram of parabolic dish

Table 2. Parabolic dish parameters

D (m)	f (m)	h (m)	A_a(m^2)	A_r(m^2)	C	A_S(m^2)
1.8	0.72	0.28	2.5	0.28	9.07	2.78

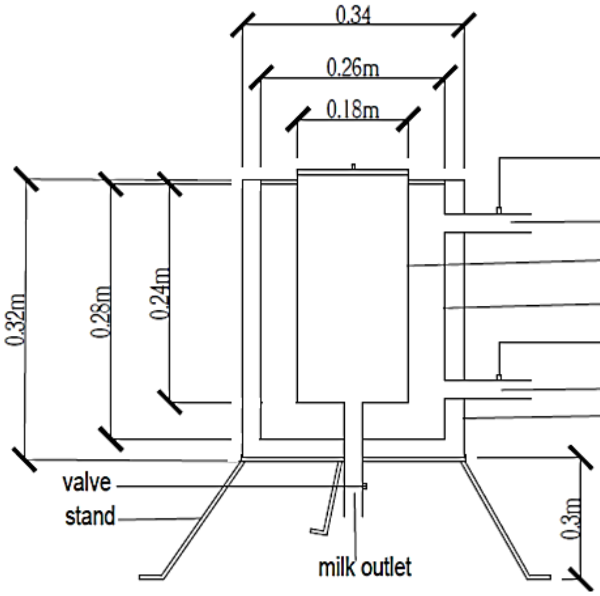


Figure 2. Design of the pasteurizing unit

Figure 3(a) experimental set-up **Figure(b)** Pasteurizing unit

2.3 Performance Evaluation of Solar Milk Pasteurizer

Heating and cooling Test

Water heating and cooling tests were done to determine the operational efficiency factor $F'\eta_O$ and overall heat loss factor F'_{UL} [13]. A receiver was used for water boiling which act as a pot to heat the water, 1.5 liter of water was heated in this experiment. The test was carried out on a clear day. The concentrator was adjusted such that the bright spot positioned on the bottom of the pot. When the water temperature reached 93 ^{o}C, the concentrator was shaded to avoid the sun rays falling on the paraboloid and cooling curve was obtained. The optical efficiency factor, $F'\eta_O$ was evaluated [13].

$$F'\eta_O = \frac{F'_{UL}}{C}\left[\frac{\left(\frac{T_{w2}-T_a}{I_b}\right)-\left(\frac{T_{w1}-T_a}{I_b}\right)e^{\frac{-\tau}{\tau_o}}}{1-e^{\frac{-\tau}{\tau_o}}}\right] \quad (6)$$

Where, $F'\eta_o =$ optical efficiency factor, $F_{UL} =$ overall heat loss factor, C = concentration ratio, $T_{w2} =$ final temperature of water, T_{w1} = initial temperature of water, I_b= solar insolation, $\tau_o =$ constant obtained from cooling curve, τ = time required to rise the water temperature from T_{w2} to T_{w1}.

The heat loss factor was determined from

$$F'_{UL} = \frac{(MC)' w}{A_p \times \tau_o} \tag{7}$$

$(MC)' w = M_{pot}.C_{pot} + M_w.C_w$

Where, M_{pot} = mass of empty pot (receiver), kg, C_{pot} = specific heat capacity of the pot (aluminum), J/kg/K, M_w = mass of water, kg, C_w = specific heat capacity of water, J/kg/K, A_p = area of receiver (pot), m^2, $\tau_o =$ constant obtained from cooling curve.

The temperature difference $(T_w - T_a)$ will fall to (1/e) of the initial value after a time $\tau = \tau_o$. Thus sensible cooling constant (τ_o) will be the time constant for the cooling and obtained from sensible cooling curve. The overall value of heat loss factor (F'_{UL}) was obtained from equation (7)

***Full load* Testing**

Full load testing of solar milk pasteurizer was performed to evaluate its performance in actually loaded condition. In this testing, 5 liters of water was heated in the vaporizer and the pasteurizing unit was loaded to its full designed capacity i.e. 6 liters in one batch and the pasteurization was performed by bubbling steam into the water jacket of the pasteurization unit. Heat losses to the surroundings was reduced by the insulation of the recipient. A valve was provided to regulate the steam flow. The valve was kept constantly opened, when the desired temperature is reached, the steam flow is closed and the milk remained in this condition for the required time. Because the specific heat capacity of milk is 3980 Jkg^{-1} K^{-1} which is less than that of water, a slight reduction in the heating time was experienced when milk was used [7]. Full load testing was first done with water and subsequently with raw milk.

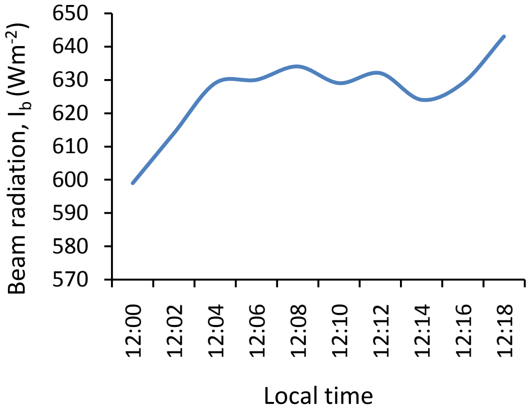
Thermal Efficiency of the system

$$\eta = \frac{heat\ required\ to\ raise\ the\ temperature\ of\ water\ from T_{W2}\ to T_{W1}}{beam\ radiation\ reaching\ the\ receiver} \times 100$$

$$\eta = \frac{M_w C_w (T_{w2} - T_{w1})}{A_r \int_0^t I_b dt} \times 100 \tag{8}$$

where, η = efficiency, M_w = mass of water, C_w= specific heat capacity of water, T_{w1} = initial temperature of water, T_{w2} = final temperature of water, A_r = area of receiver, I_b = solar insolation, t = time

III. RESULTS AND DISCUSSIONS



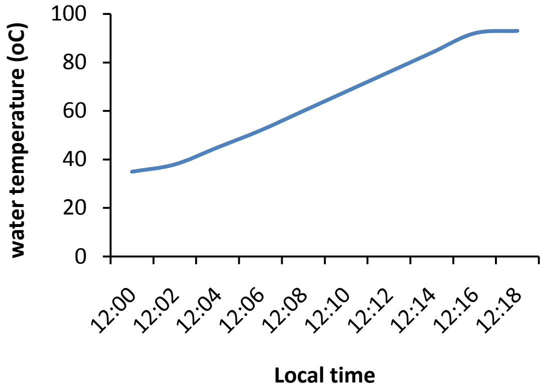


Figure 4(a) Figure 4(b)

Figure 4. Plot of beam radiation against local time (a) rise water temperature against local time (b)

Table 3. Initial and final temperature of water, ambient temperature and solar insolation during heating test

T_{w1} (°C)	T_{w2} (°C)	T_a (°C)	I_b(Wm^{-2})
35	93	37	626

Fig. 4(a) depict the plot of water temperature against local time, the water temperature was found to increase with increase in beam radiation received, as the water temperature approaches boiling point the linear proportionality begins to break, this is due to heat lost from the absorber to the surrounding. From the heating test the temperature of water increased from initial temperature of 35°C to 93°C for the period of time τ. Using the data in table 2, the optical efficiency factor $F'\eta_o$ of the collector was evaluated from equation (6) and the overall heat loss factor F_{UL} was determined using equation (7).

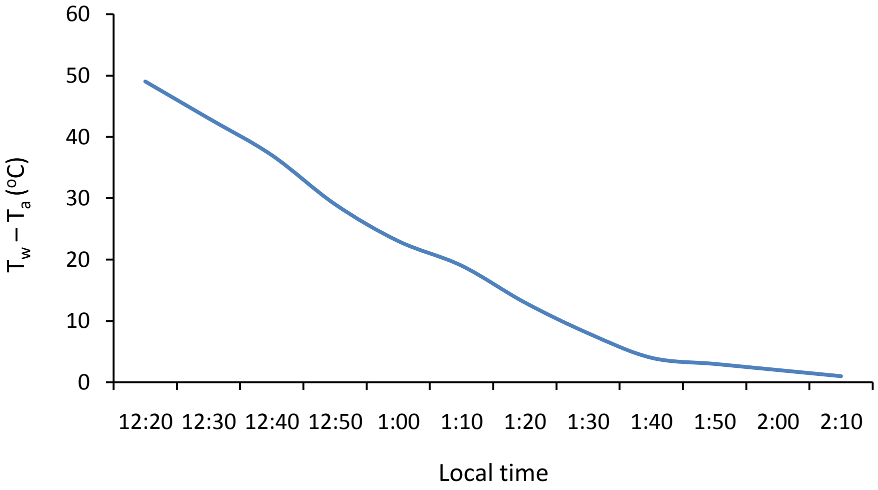


Figure 5. Cooling Curve

Full Load Water Test Result

Table 4. Data of full load water test

Local time	Water temp. (°C)	Water tank temp. (°C)	Ambient temp. (°C)	Beam radiation, I_b (Wm^{-2})
11:00	30	36	36	612
11:20	31	38	37	639
11:40	35	42	36	609
12:00	44	49	37	626
12:20	70	48	37	621
12:40	**90**	45	37	634

From Table 4, the water inside the milk tank attained a temperature of 90°C in 100 minutes, which is far above the pasteurizing temperature of milk. Figure 6, present the plot of data obtained from the full load of water test, the result shows a linear increase in water temperature with little drop in the value of beam radiation which has not affect the heating time significantly. The water tank (steam tank) temperature started increasing before declining, the decline is due to the heat absorption by the milk tank. The ambient temperature is nearly constant for the period of the test.

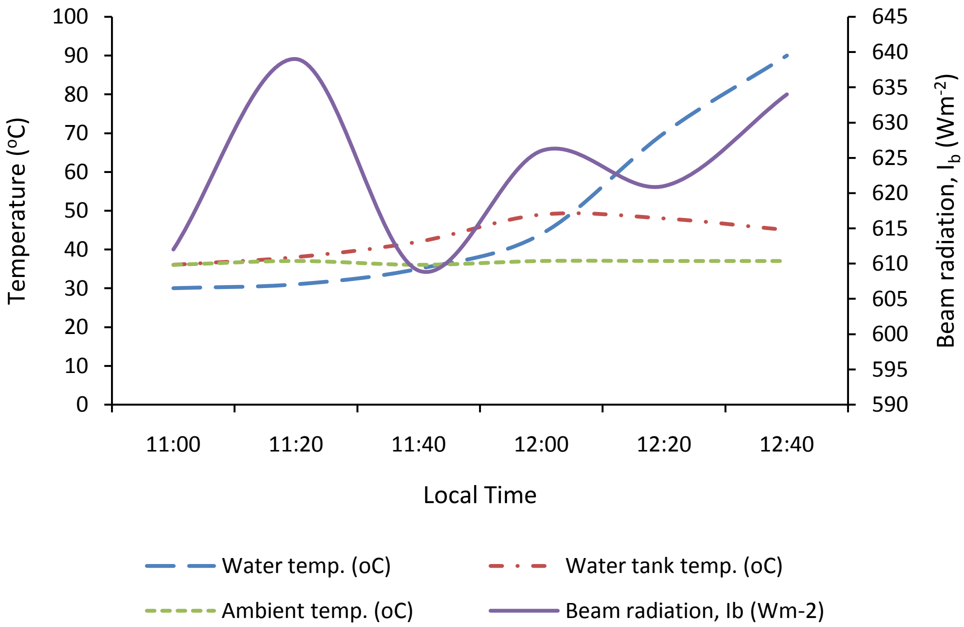


Figure 6. Plot of water temperature, water tank temperature, ambient temperature and beam radiation for full load water test

Full Load Milk Test Result

The full load milk test was carried out on a clear sky condition for two days, three types of pasteurization (Low heat pasteurization, High heat pasteurization and Flash pasteurization) were attained at their corresponding temperatures.

Table 5. Data of full load milk test for day one

Local time	Milk temp. (°C)	Water tank temp. (°C)	Ambient temp. (°C)	Beam radiation, I_b (Wm^{-2})
11:40	30	32	37	660
12:00	32	36	36	638
12:20	42	45	36	646
12:40	**64**	48	37	647
12:50	**73**	46	38	651
01:05	**89**	43	37	654

The results from full load milk test for day one in Table 5 shows that low-heat pasteurization was attained in 60thminute, high-heat pasteurization was attained in 70thminute and flash pasteurization was attained in 85thminute. This results shows a good reduction in time. Figure 7, shows an increase in water temperature which is almost linear, after initial drop in the value of beam radiation. This increase necessitates the reduction in pasteurizing time. Increase in beam radiation is a determining factor in pasteurizing time. It is observed that continuous increase in beam radiation after an initial fall leads to decrease in pasteurization time. This means, the two variables are inversely proportional.

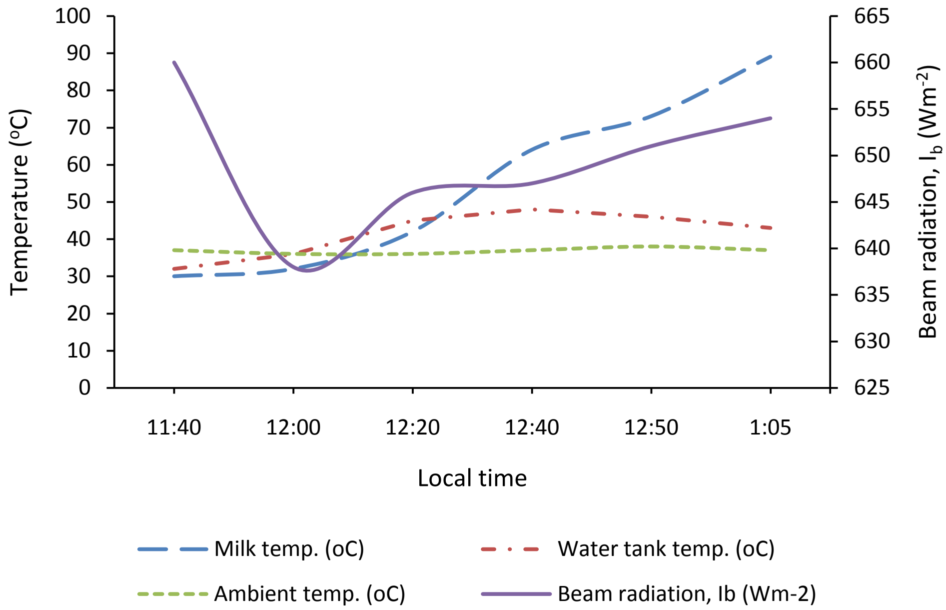


Figure 7. Graph of milk temperature, water tank temperature, ambient temperature and solar insolation for full load milk test for day one

Table 6. Data of full load milk test for day two

Local time	Milk temp. (°C)	Water tank temp. (°C)	Ambient temp. (°C)	Beam radiation, I_b (Wm^{-2})
12:20	33	33	36	674
\12:40	33	34	37	654
01:00	43	44	36	579
01:20	54	45	37	574
01:40	**63**	46	36	556
01:50	**72**	47	36	511
02:10	**89**	43	37	534

The results of the full load milk pasteurization in Table 6 shows that, low-heat pasteurization was attained in 80 minutes, high-heat pasteurization was attained in 90 minutes and flash pasteurization was attained in 110 minutes. From the plot presented in Figure 8, it shows that the increase in pasteurization time was due to the re-occurring fall in value of beam radiation for the period of the pasteurization, which leads to the delay in pasteurization. The fall in the water tank temperature is because of the heat been absorbed by the milk tank. The change in ambient temperature is insignificant.

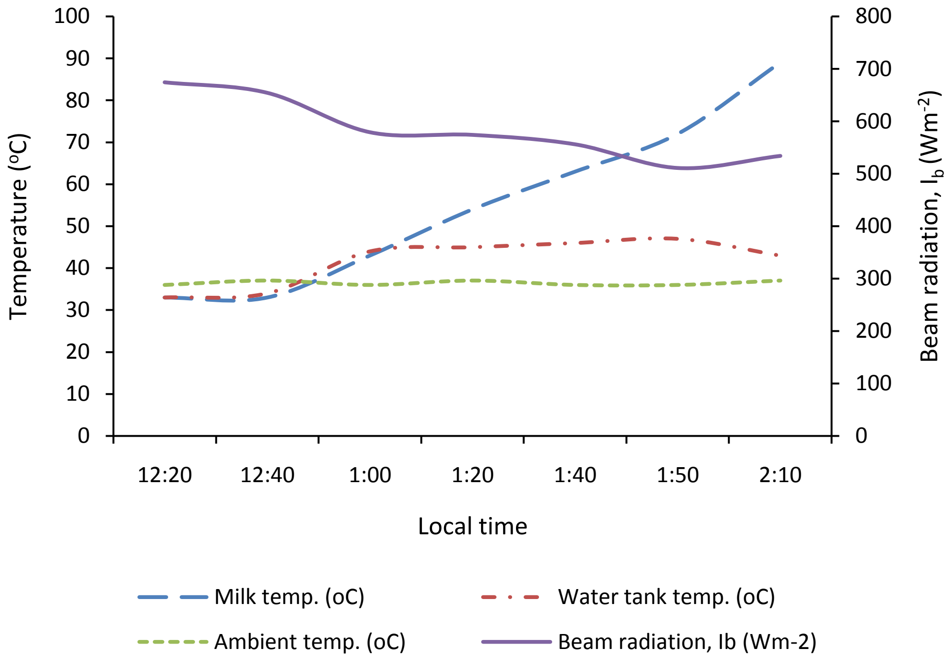


Figure 8. Graph of milk temperature, water tank temperature, ambient temperature and solar insolation for full load milk test for day two.

Performance of the Solar Parabolic Dish Milk Pasteurizer

The performance of the system was evaluated from water heating test. Determination of thermal efficiency is the other criteria for computing the performance of paraboloid solar concentrator under different climatic conditions. The efficiency was obtain using equation (8).

Table 7. Performance results

$(MC)'_w$ (JK^{-1})	τ_o (s)	τ (s)	F'_{UL} ($WK^{-1}m^{-2}$)	$F'\eta_O$	η (%)
7298.1	3660	1080	7.12	0.28	56

IV. CONCLUSION

Solar energy as a renewable form of energy is free in nature, its cleanliness makes it an environmental friendly energy resources, it helps in the conservation of natural habitation. Using solar energy for milk pasteurization is a means of providing safe milk for human consumption without polluting the environment and economically it reduces the use of conventional energy resources. Pasteurization of milk using solar energy helps to preserve more of the natural nutrients of the milk and its gustatory quality by the application of steady heat. The availability of solar insolation in Yola makes it a favorable place for the smooth operation of solar devices. The construction of the solar parabolic dish milk pasteurizer was done and tested in Yola under clear sky condition between the hours 11:00 am and 3:00 pm. Low heat pasteurization, high heat pasteurization and flash pasteurization were performed. From the test results the optical efficiency of the collector was found to be 0.28, the heat loss factor was found to be 7.12 $WK^{-1}m^{-2}$ and the system efficiency of 56%. The availability of cow milk and high rate of milk consumption in Yola, makes the solar milk pasteurizer is an ideal system of complementing or good replacement for conventional energy for milk pasteurization in Yola.

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