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Research Paper

Development of a Solar Milk Pasteurizer for Improved Performance

Vincent Enebe[1], Abdulkarim Nasir[2], Anthony Joachim Omeiza[3], OkenyiOscarline Okwudili[4]
[1]*(Department of Mechanical Engineering, Modibbo Adama University, Yola, Adamawa State.)*
[2,3,4]*(Department of Mechanical Engineering, Federal University of Technology, Minna, Niger State.)*

ABSTRACT:*The consumption of un-pasteurized dairy products has been found to be a channel for the transmission of zoonotic diseases to man. In an attempt to solve this problem and ease the energy needs of the people, conventional fossil fuel for heating purposes has been studied. A solar milk pasteurizer system which traps and made use of the abundant solar energy to provide domestic pasteurized milk was developed and tested. The system consists of a flat plate solar collector of a total area of 4.3 m^2 with helical copper tubes capable of circulating 20 litres of water wound round a 20 litres milk vat. The system pasteurised 14 litres of milk whose temperature rose to 63^o C with a retention period of 30 minutes conveniently by exchanging heat with water at a temperature of 90^o C. Microbiological analysis performed on the pasteurized 14 litres of milk showed that the milk was negative to total Coli-form count, total faecal count and Staphylococcus. The total bacteria count and Fungi recorded from the pasteurized 14 litres recorded was 4cfu/ml each, which was below the US standard of 100cfu/ml.*

KEYWORDS: *Pasteurization, pasteurizer, solar plate collector, heat exchanger, fungi, bacteria-count.*

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I. INTRODUCTION

Heat transfer has become an important component of engineering due to the use of engineering to promote efficient energy consumption. Heat transfer has a significant impact on product quality and human lifestyle as heating and cooling systems are commonly used to control heat flow. The use of thermal insulations, thermal exchangers, and other supporting equipment is relevant to human concerns. A heat exchanger is a form of heat transfer device and by definition, thermal devices and heat exchangers transfer heat from one fluid flow to another[1].Heat exchangers have long been used in the liquid food processing business[2].

Temperature control loops are commonly used with heat exchangers in heat transfer operations to maintain a precise and consistent temp. Temperature affects both product quality and health when it comes to food heat treatment. However, harmful organisms require foods that have been prepared to a specific temperature, according to[3]. In a system, the fluid composition affects pressure drop and heat transfer. Milk and its components are essential to human nutrition[4]. Milk is rich in minerals, vitamins, fats, and protein. As a result of these qualities, milk becomes an important and complete diet in itself. Lactobacillus spoilage germs thrive in perishable milk if incorrectly handled[4]. Safe milk has 5106 bacteria per milliliter, according to[5].

Most infectious diseases including diarrhoea, typhoid, and cholera are believed to be spread through infected liquids and food (including milk) in developing countries [6]. An estimated 400 children every hour and over 4 million per year die from diarrhea according to WHO estimates (W.H.O). Ingestion of unheated water and liquid meals has been linked to serious morbidity. Animal and human contamination has resulted in a thousand faecal bacteria per decilitre surface water. Toxic cow diseases like typhoid, brucellosis, and tuberculosis were transmitted to humans via fresh raw milk, says [7]. Pasteurization is therefore required to make drinking water and dairy products safe.

To destroy most disease-causing organisms, surface water is pasteurized using sun light. Similarly, warm water is circulated around a milk vat, transferring heat to the milk, eliminating most bacteria. A solar panel converts the energy of the sun's rays into heat, according to[8], enabling this procedure. In order to evaluate the efficiency of a solar pasteurizer with copper tubes, this study redesigned a solar pasteurizer with copper tubes and a water jacket

II. RELATED WORKS

A system in [9] designed a pasteurizer using the indirect heating which is three times more effective and reduces the area of the solar collector by 50%. The indirect method is also applicable in the cooking area where the solar collector is situated far away from the actual cooking is done. The work in [10]designed and developed a locally fabricated solar milk pasteurizer with a solar collector area of $1.5m^2$ to heat the milk to a temperature between 63^0C to 70^0C. A paper in [11]also developed a milk pasteurization unit and included a pneumatic regulating valve to improve its performance. The results revealed that pasteurization unit productivity, fuel consumption, energy requirements, and bacteria count were in the optimal region in the given conditions of heating temperature of 74^0C, vapor pressure of 400kPa, and cooling temperature of 4^0C. A flat plate water heating collector for milk pasteurization was designed in[12]. This design was an improvement on the design in [6]. A 1.5 mm thick stainless steel cyclindrical milk vat with a capacity of 80 L and a 50 mm wide hot water jacket installed with 38 mm thick fiber glass insulator were constructed and tested in an arid pastorial area of Northern Kenya for the performance assessment of the flat plate solar pasteurizer. Milk was pasteurized using hot water generated by the flat plate collector, with a maximum yield of 40 liters of pasteurized milk. Between the hot water and the pasteured milk, an average temperature difference of 8.1°C 1.4°C was found. The work in [12], on the other hand, built a cooking unit with two walls, a storage tank, and a positive displacement pump. The heat transfer fluids are Thermiol 55 and D-mannitol. also created a solar water heater that could be utilized in the pasteurization system for milk. The water that had been heated in an accumulator was used as a direct heating source for milk to be pasteurized. The result showed that the it took 12 minutes to reach the required temperature for pasteurization when 82^0C of heated water was in the thermos. Indumathy, et al. [9] developed a dynamic model for high temperature short time pasteurization process using plate-heat exchangers. The sections of the real time HTST process and they were modelled using Matlab. The results obtained depicted that the linear models corresponded to the plant-data.

Most of the developed designs are based on the conventional milk vat in water jacket principle, stationary and the cost of producing a unit beyond the financial capacity of most households as designs are based on industrial or communal usage. However, developing a design in which the surface area in contact with the milk vat is improved on will be efficient in pasteurizing milk without compromising in the performance efficiency is what this thesis seeks to address.

III. METHODOLOGY

The selection of materials for the solar pasteurizer is done based on the following criteria:

i. Availability of material in local market.
ii. Initial cost of material
iii. Health implication of material
iv. Weld ability of material.

The developed pasteurizer uses a flat plate solar collector, glass as preferred glazing material, tubes and absorber plates, thermal insulators, rivets, and a thermometer for observing temperature readings. The easy-to-install flat plate collector uses both diffused and direct beams for solar radiation. Because of its capacity to transmit solar energy, low reflectance, (p), low absorptance, (a), and high transmittance, glass was chosen as the glazing material for this investigation (t). Because of its high conductivity and compatibility with water, copper tubing is selected for usage as absorber plates, whereas fibre glass-wool and hard foam are used to insulate the flat plate, storage tank, and connecting pipes. Rivet pins are utilized as fasteners to attach the various components of thepasteurizer system together during assembly.

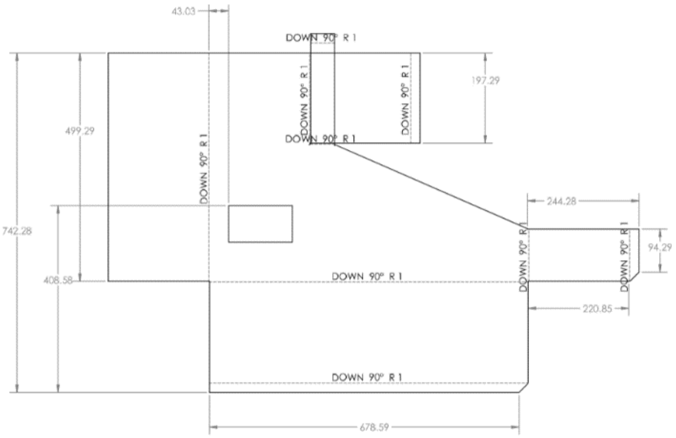

Figure 1:

Determination of Quantity of Heat Required

The goal of designing a solar collector heat exchanger is to relate the following; (i) the inlet and outlet temperatures (t_1 , t_2), (ii) the overall heat transfer coefficient (U) due to the various modes of heat transfer and (iii) the geometry of the heat exchanger (that is the total surface area of the heat transfer). The basic principle of heat transfer for a heat exchanger is the foundation up on which this design is based. The enthalpy balance on either fluids stream is given as

$Q_w = \dot{m_w} \ (h_{w_1} - h_{w_2})$ 3.9

$Q_m = \dot{m_m} \ (h_{m_2} - h_{m_1})$ 3.10

For constant heat transfer with no phase change we have

$Q_w = \dot{m}_w c_{pw} \left(T_{w_1} - T_{w_2}\right)$ 3.11

$Q_m = \dot{m}_m c_{pm} \ (T_{m_2} - T_{m_1})$ 3.12

From energy conservation, it is known that $Q_w = Q_m = Q$ and that the heat transfer rate Q and the overall heat transfer coefficient U, can be related to the sum mean temperature ΔT_m by means of the equation below.

$Q = UA\Delta T_m$ 3.13

where $\dot{m}_w$ is the mass flow rate of water.
$\dot{m}_m$ is the mass flow rate of milk.
h_w and h_w are the enthalpy of water and milk respectively.
c_{pw} and c_{pm} are the specific heat capacity of water and milk respectively.
T_w and T_m are the temperatures of water and milk.
U is the heat transfer coefficient
A is the area in concern of the heat transfer.
T_m is the sum mean temperature.

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c_{pw} and c_{pm} are the specific heat capacity of water and milk respectively.
T_w and T_m are the temperatures of water and milk.
U is the heat transfer co-efficient
A is the area in concern of the heat transfer.
T_m is the sum mean temperature

Determination of Solar Collector Area(A)

The solar pasteuriser uses solar heat from the pasteurise milk at a temperature of $65°$. The collector area required to heat up the milk to this temperature is given by

$Q_u = A_c F_R [S - U_L\left(T_{pm} - T_a\right)]$ 3.14

where F_R is the the heat removal factor
U_L is the total heat loss coefficient
A_c is the flat plate collector area (m^2)
S is radiation absorbed per unit area
T_{pm} is the mean system temperature.

[13] warned that the problem with equation $3.2.2_b$ is that the mean system temperature is difficult to calculate or measured though it is expressed as:

$$T_{pm} = T_a + \frac{Q_U}{U_L A_C}[1 - \frac{F_R}{F}] \qquad 3.15$$

Determination of Solar Collector Heat Removal Factor

The collector heat removal factor, FR, is defined as the ratio of a collector's actual usable energy gain to the useful gain if the entire collection surface were at the fluid input temperature (i.e., the complete collection surface was at the fluid input temperature). It has an efficiency that is comparable to that of a heat exchanger. According to[13], the collector heat removal factor for a header-riser flat-plate collector is as follows:

$$F_R = \frac{\dot{m}C_p}{A_c U_L}\left[1 - exp\left(-\frac{\dot{m}C_p F'}{A_c U_L}\right)\right] \qquad 3.16$$

where: F_R is the heat removal factor

$\dot{m}$ is the mass flow rate of collector fluid

C_p is the specific heat capacity of the fluid

A_c is the area of the collector

U_L is the overall collector loss coefficient.

F' is the collector efficiency factor defined by Duffie and Beckman 2013 as:

$$F' = \frac{{}^{1}/_{U_L}}{W\left[\frac{1}{U_L(D_i+(W-D_i)F)} + \frac{1}{C_b} + \frac{1}{\pi D_i h_{f_i}}\right]} \qquad 3.17$$

where: W is the tube spacing

C_b is the contact resistance and $\frac{1}{C_b}$ is zero

D_i tube internal diameter

h_{f_i} is the internal fluid heat transfer coefficient

F is the standard efficiency for straight fins and rectangular profile, expressed as (Duffie and Beckman, 2013)

$$F = \frac{\tanh\left[\frac{m(W-D_i)}{2}\right]}{\frac{m(W-D_i)}{2}} \qquad 3.18$$

where: $m = \sqrt{\frac{U_L}{k\delta}}$ 3.19

$k\delta$ is the plate's thermal conductivity and thickness product.

Duffie and Beckmannopined that for the fin efficiency (F), there is a decrease in the magnitude of heat transfer by thee fin when compared to the magnitude of heat transfer when all are at constant temperature[13].

Collector Overall Heat Loss Coefficient (U_L).

The overall heat loss coefficient of a solar plate collector is the sum of the top, edge, and rear losses. For example, according to[13]uf:

$$U_L = U_t + U_e + U_b \qquad 3.20$$

Collector Top Loss Coefficient (U_t) .

Duffie and Beckman 2013, expressed an approximate relation for the collector top loss coefficient (U_t) as:

$$U_t = \left(\frac{N}{\frac{C}{T_{pm}}\left[\frac{T_{pm}-T_a}{(N+f)}\right]^e} + \frac{1}{h_w}\right)^{-1} + \frac{\sigma(T_{pm}+T_a)(T_{pm}{}^2+T_a{}^2)}{\frac{1}{\varepsilon_p+0.00591\,N h_w}+\frac{2N+f-1+0.133\,\varepsilon_p}{\varepsilon_g}-N} \quad 3.21$$

where

$f = \left(1 + 0{,}089h_w - 0.1166h_w\varepsilon_p\right)(1 + o.07866N)$ 3.22

$C = 520(1 - 0.000051\beta^2)$ for $0° < \beta < 70°$; $70° < \beta < 90°$, use 70°. 3.23

$e = 0.430 \left(1 - {}^{100}/_{T_{p_m}}\right)$ 3.24

$\beta =$ Collector tilt (deg)

$\varepsilon_g =$ Glass emittance (0.88 [13])

$\varepsilon_p =$ Plate emittence.

$T_a =$ Ambient Temperature

$T_{p_m} =$ Mean plate Temperature

$h_w =$ Wind heat transfer coefficient $({}^{W}/_{m^2.K})$

Collector Back Loss Coefficient $(\boldsymbol{U_b})$.

The bottom of the collector loses energy due to heat flow resistance in the insulation and environmental resistance via convection and radiation.[13], puts it that the magnitude of conduction loss in comparison to radiation loss, is such that radiation loss can be assumed zero and they therefore relate back loss coefficient $\boldsymbol{U_b}$approximately as:

$$U_b = {}^{k}/_{L} \qquad 3.25$$

where k and L are the insulation thermal conductivity and thickness respectively.

Collector Edge Loss Coefficient $\boldsymbol{U_e}$.

The evaluation of edge losses for the majority of collectors is time-consuming and difficult. As a result, a well-designed system does not necessitate the ability to estimate the edge loss with high accuracy. It is calculated by multiplying the ratio of the thermal conductivity of the insulation at the edge by the thickness of the insulation at the edge by the ratio of the area of the edge to the total area of the collector.

$$U_e = \left(\frac{k}{L}\right)_e \cdot \left(\frac{A_e}{A_c}\right) = \frac{(UA)_e}{A_c} \qquad 3.27$$

Collector Efficiency

The collector efficiency is the measure of the performance of solar collector system. This can be expressed in a number of ways. One of the ways is by expressing it as a ratio of useful energy gain over anytime period to the incidence solar radiation energy (Duffie and Beckmann, 2013).[13]

$$\varepsilon_c = \frac{Q}{A_C I_o} \qquad 3.2$$

The collector efficiency and fin efficiency of a natural circulation solar heater are considered performance metrics).

Collector Tubes Convective Heat Transfer Coefficient.

The Reynolds, Prandtl, and Nusselt numbers are used to calculate the convective heat transfer coefficient in a collector tube. The values of the parameters defining these figures are likewise temperature dependant, therefore determining the exact temperature at which an evaluation should be performed is impossible. The Reynolds number (Re) is then used to define the flow's type, i.e., if Re is less than or equal to 2200, the flow is said to be laminar, and if Re is larger than 2200, the flow is said to be turbulent[1]. The Reynolds number indicator is also useful in calculating the Nusselt number (Nu), which is utilized in convective heat transfer calculations.

[14]stated a general correlation for calculating the convective heat transfer coefficient in tubes as follows:

$$h_f = \frac{k_f Nu}{D_i} \qquad 3.28$$

where

h_f is the convective heat transfer co-efficient
k_f is the thermal conductivity of the fluid inside the tube.
Nu is the Nusselt number
D_i is the inernal diameter of the tube.

For laminar flow, like in a thermosyphon system, the Nusselt number, which is a function of the Reynolds number, can be determined. [15]correlated Nu for a turbulent flow with Re larger than 2200 as:

$$Nu = \frac{(f_n/8)RePr}{k_1 + k_2(f_n/8)^2(Pr^{2/3} - 1)} \qquad 3.29$$

where

$$k_1 = 1 + 1.3f_n \qquad 3.30$$

$$k_2 = 11.7 + \frac{1.8}{Pr^{1/3}} \qquad 3.31$$

$$f_n = [1.82\log(Re) - 1.64]^{-2} 3.32$$

Flow is deemed laminar when Re is less than 2200, and [15]found that the Nusselt number for such a flow is given by:

$$Nu = 3.7 + \left[\frac{0.0534\left(\frac{RePr\ D_i}{L}\right)^{1.15}}{1 + 0.0335\left(\frac{RePr\ D_i}{L}\right)^{0.82}}\right] \qquad 3.33$$

where:

Re is the Reynolds number is expressed as:

$$Re = \frac{4\dot{m}}{\pi\mu\, D_i} \qquad 3.34$$

Pr is the prandtl number expressed by [13], as:

$$\mathrm{Pr} = \frac{C_p\mu}{k_f} \qquad 3.35$$

where
Nu is the Nusselt number
D_i is the tube inner diameter.
$\dot{m}$ is the fluid flow rate
μ is the dynamic viscocity of fluid
C_p is the specific heat capacity of the fluid
k_f is the fluid thermal conductivity
L is the tube length.

IV. RESULTS AND DISCUSSION

Raw milk samples were filled into the milk vat and heated water within the copper pipes wound round the milk vat heated up the milk within the vat. Ten different experiments were carried out with the volume of milk been varied at each experiment. Pasteurisation temperature was recorded for each experiment after 30 minutes with the aid of thermometer. Other results were obtained by thermal calculations. Emphasis were placed on milk water variation in samples (C), (D) and (E) among the results obtained since these were where the actual pasteurization took place, these provided good explanation for which the experiment was carried out.

Table 1.0: Variation in water and milk temperature in the SMP against time.

Local Time	C			D			E		
	Water Temp(^{0}C).		Milk	Water Temp(^{0}C).		Milk	Water Temp(^{0}C).		Milk
	Inlet	Outlet	^{0}C	Inlet	Outlet	^{0}C	Inlet	Outlet	^{0}C
9.00	30	7.7	27	32	9.7	27	35	12.7	27
10.00	35	28	35	40	31	37	43	33.9	38
11.00	47	39.7	35.8	49	39.1	39	50	37.6	42
12.00	59	40	49	60	39.4	52	59	39.2	51
13.00	75	49.4	58	76	48.9	60	78	51.6	59
14.00	90	69	63	90	69	63	90	69	63
15.00	85	57.8	60	83	54.9	61	85	58.6	59
16.00	70	46.9	55	80	53.6	59	81	57.9	55

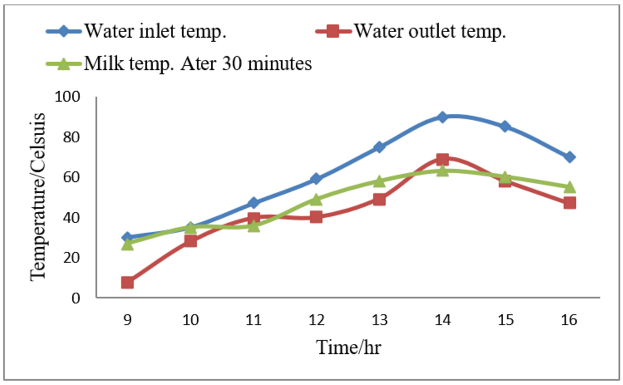

Figure 1: Graph of variation in water and milk temperature in theSMP against time for experiment C.

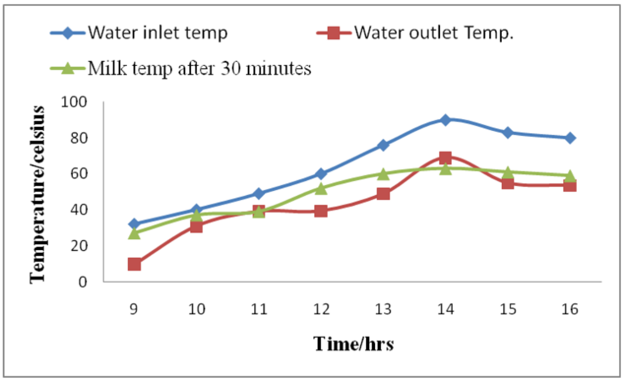

Figure2: Graph of variation in water and milk temperature in theSMP against time for experiment D

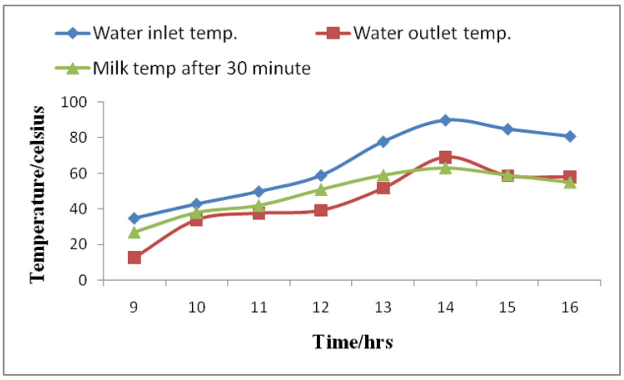

Figure3: Graph of variation in water and milk temperature in theSMP against time for experiment E.

V. CONCLUSION

The contribution to knowledge from the analysis and experiments carried out is the introduction of copper pipes round the milk vat in other to increase the surface area in contact with the milk and thus increasing the heat exchange rate without compromising with the quality of pasteurized milk produced. This will greatly contribute to the eradication of zoonotic diseases and improve on human health.

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