Journal of NIMechE Vol. 8, No.2, pp 176 - 202
Printed in Nigeria

ISSN 2141- 2987
Copyright @ 2018, The Nigerian Institution of Mechanical Engineers (A Division of The Nigerian Society of Engineers)

HEAT EXCHANGER DESIGN FOR A NEW TECHNOLOGY OF MILK PASTEURIZATION

***M. D. Bako[1], F. O. Akinbode[2], A. Nasir[3], M. M. Muhammadu[4] and Y. Kabir [5]**

[1,2,3&4] *Department of Mechanical Engineering, School of infrastructure, Process Engineering and Technology, Federal University of Technology, Minna, Nigeria.*
[5] *Department of Biochemistry, School of Life Science, Federal University of Technology, P. M. B. 65, Minna, Nigeria.*
* Corresponding author: bako.danladi@yahoo.com

Abstract

Heat exchanger-versatile equipment which finds its application in both industrial and domestic environment was designed with the principle of short concentric tubes with recycling heat transfer technique. The heat exchanger was designed to ascertain its viability of solving the problem of cost effectiveness, reduction of space and micro-scale pasteurization of milk product. Raw milk carries pathogenic organisms which are disastrous to human health. Good quality milk should be suitable to consume, free of micro-organisms and toxic compounds. Milk is not pasteurized before consumption in many areas of the third world countries. Poor milk consumption in Africa has led to the loss of many lives and poor health condition through diseases such as cholera, diarrhea, tuberculosis and enteric fever etc. It is therefore, required that effort should be made to improve on the quality of local milk being consumed in Africa. The idea of recycling in heat exchange is cost effective as compared to arrangement of pipes and plates heat exchangers. The concentric tube heat exchanger developed used 40litres of water at 90^{0}C to pasteurize 30litres, 25litres and 20litres of raw milk, 63^{0}C for 30 minutes on continuous bases. The bacteriological results obtained before and after pasteurization showed a good treatment of the milk. The new technology named cycle pasteurization is expected to complement the existing conventional means of Batch and Flash pasteurization which is characterized with the challenge of micro- scale pasteurization of milk product.

Keywords: short concentric tube, heat exchanger, low temperature, long time, micro-scale and cycle pasteurization

1.0 INTRODUCTION

Heat Transfer has been an integral part of industrial development as we strive to improve on the efficient use of energy. This implies that heat transfer applications in both industrial and residual processes have affected the quality of eaten food, living and life style. As such, heat transfer is of particular importance in engineering field where understanding and control of heat flow through heat exchangers, thermal insulation and other supporting devices are used continuously to solve basic or fundamental human problems (Greiner, 2000).

Heat exchangers have become an essential component in the process lines of the liquid food industry for many years. The application of heat exchanger in milk processing plant involves movement of liquid milk from one location to another which then becomes an essential or critical operation. The flow of liquid milk by a system is directly related to its properties, primarily viscosity and density. These will influence the power requirements for the liquids to flow as well as the flow characteristics within the pipeline. An understanding of the physical meaning associated with these properties is necessary in order to design or develop a new design from the existing designs with an optimization and sound method for measurement of its properties. Corrosion is also a major factor in low temperature heat transfer of fluids because they are water based. Thus, a careful study of material for thermal food processing is imperative for enhancement of the design objectives. Overall, thermal processing has been regarded as the ultimate "safe harbor" for milk safety, it should be clear that it is one of those technologies where a critical understanding and appropriate application of all requirement in thermal processing design cannot be overlooked (Holdsworth, 1985*)*. The conference of the World Health Organization of 7th April, 2011 concludes that anti-microbial resistance is not a new problem but one that is becoming more dangerous; urgent and consolidated effort are needed to avoid outbreak of un-combatable spread of diseases. Hence, the theme at the event was "Anti-microbial resistance; no action today, no prevention and cure tomorrow".

Heat Transfer to milk is common place but critical; tactical heating has to be developed to maintain good flavor and texture, and ensures product safety for consumption (Peter and Phillip, 2005). Pasteurization as applied to milk means the exposure of the products to a heat treatment which will destroy pathogenic organisms and yet not alter the taste, flavour or composition of the product. Pasteurization typically uses temperature below boiling since at very high temperature, it will irreversibly aggregate **(or "curdle")**. Louis Pasture cites general guide lines of 145^{0}F (63^{0}C) for 30 minutes for batch pasteurization and 162^{0}F (72°C) for 15 seconds for flash pasteurization (IDF, 1994). A good quality milk is suitable for consumption and should have a minimum of microorganisms and toxic compound. Moreover, it must not be less in essential nutrients of the standards set by the Ministry of Health. (Noppawwan, 2005).Conventional pasteurization facilities in existence are only obtainable using heat exchangers with complex, expensive and non-cost effective in designs and constructions that have made it impossible for pasteurization on micro-scale basis. In developing countries like Nigeria, few of these facilities only exist because of the cost and as such products from these facilities are also very expensive for the low income earners whom are the majority. Yet fermentation (souring) which is being practice only lowers the pH of milk from about 6.8 to about 4.5. Hence, brucella organism are only mildly affected (Farrell, 1996). Minja (1999), in a similar study found out that the low pH level in sour milk only destroys mycobacterium bovis after 66 hours. This implies that home-made fermented milk isLocal milk producers should therefore be educated on the importance of pasteurization and making these regulations mandatory for milk intended for human consumption (Bertul, *et al*, 2009).

Plate 1: Concentric Tube Exchanger Facility (Source: MGT Process Diaries)

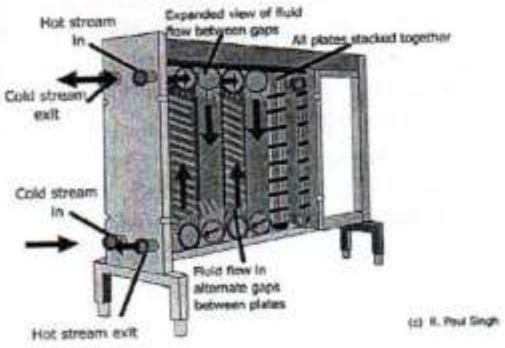

Plate 2: Plate Heat Exchanger Facility

The problem been faced by heat transfer engineers in the milk industry has been that of how to down-scale the producing plant. It is difficult to specify the physics in such a way as to allow accurate prediction of the process (Amin and Ali, 2012). Good modeling methods must be developed to help the process design and control specification. The application of recycled heat transfer technique over a Short Concentric Circular Tube provides a medium to which the heat transfer area of the Heat Exchanger can be significantly constrained to a reduce size. Hence, rather than measuring the heat transfer area in terms of tube length, it would be measured in terms number of recycles per tube length. This phenomenon is referred to in simple term as Cycle Pasteurization.

One of the most important requirements of modern dairying is to be able to control the temperature of products at every stage in the process. Heating and cooling are therefore very common operations in the dairy. Milk is heated by a heating medium such as low-pressure steam (very seldom used nowadays) or hot water. The heat flow between mediums is a direct function of the temperature difference between the two fluids, the area where heat is transferred, and the conductive and convective properties of the fluid and the flow state (Akash, 2011). In all cases heat is exchanged from the hot to the cooling medium. This process in a heat exchanger is called *regenerative heat exchange* or, more commonly, *heat recovery* (Bylund, 1995). Correct heat treatment requires that the milk is held for a specified time at pasteurization temperature. This is done in an external holding cell. The lengths of the pipe and flow rate are calculated so that the time in the holding cell is equal to the required holding time. Holding sections built into the heat exchanger were used earlier, but external holding cells are used almost exclusively nowadays.

2.0 Literature Review

Conventional heat exchanges are devices in which two fluid streams, separated from each other by one solid wall, exchange thermal energy: one stream is heated while the other is cooled (Kreith and Kreider, 1978). Heat exchangers are typically classified by flow arrangements and type of construction the simplest being one for which the hot and cold fluids move in the same or opposite directions in a concentric tube construction (Lienhard, 2005). Usually, the two fluid streams are commonly classified according to flow arrangement and construction type (Incropera and Dewitt, 2002). In a rather specific and analytic view point, Eckert and Drake (1987) have it that there are three heat transfer operations that need to be considered when carrying out the design of concentric tube heat exchanger.

Parrot (1978) has it that the temperature difference and heat transfer coefficient at any point in the equipment control the rate of heat exchange. He also observed that the fluids could flow in the same direction through the equipment and in the opposite directions.

(Rennie (2004), performed numerical and experimental studies of double pipe helical heat exchanger, the experimental stride of double pipe helical heat transfer and hydrodynamic characteristics was carried out. The achievement gave way for little economy of space but the problems of cost effectiveness persist.

Plate 3: Coiled double pipe helical heat exchanger (Rennie, 2004)

Rabab,Hafiz, Nasir, Muhammad and Zia-ul-Haq (2009), a solar milk pasteurizer (SMP) was fabricated to investigate the potential of using solar energy to pasteurize natural milk. Milk samples were collected and the inactivation of microbes took place using the energy. This experimentation was done on temperature ranging from 65°C to 75°C. The base and inner space temperature of the milk were then recorded and found to have the same values as 65°C and 75°C respectively. It provides a practical, low-cost milk pasteurizer for the improvement of drinking milk quality in developing countries like Pakistan. However, the deficiency of the Solar Milk Pasteurizer is that of space economy, long duration of pasteurization and availability of Sun light at a time.

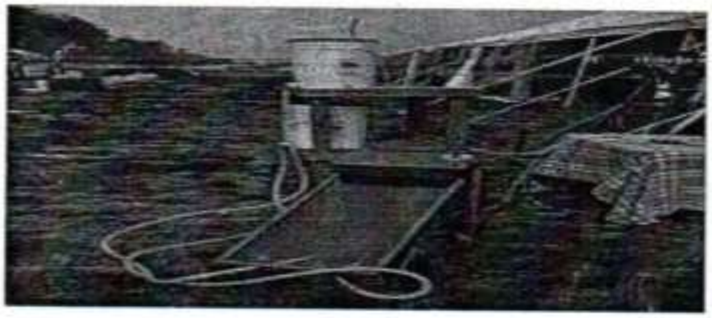

Plate 4: Solar Milk Pasteurizer

3.0 Materials and Methods

3.1 Working Principle of the pasteurizer

The process flow design is depicted in the figure 5 below in accordance with the literature requirement. All process requirement of pasteurization is sequentially represented by the process flow design and the schematics of the heat exchanger design in figure 6 below also.

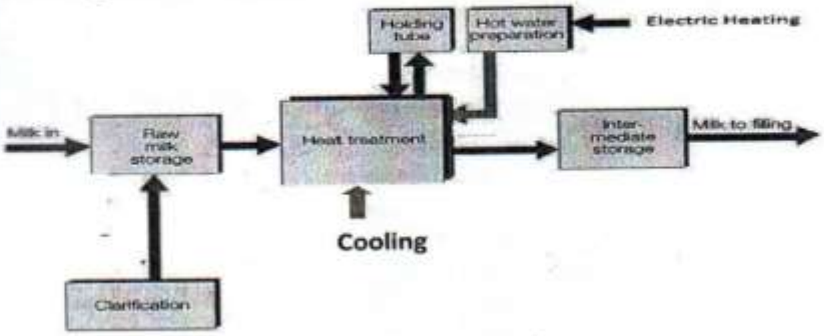

Figure 1: Process Flow Design (Bylund, 1995)

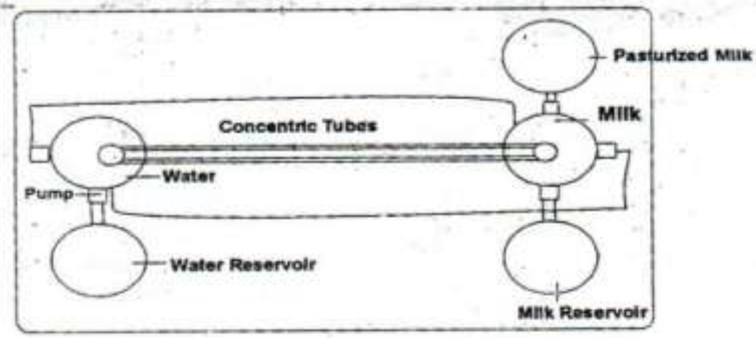

Figure 2: Schematics of the process flow design

3.2 Methodology of Fabrication

The choice of plastic materials instead of metal materials such as copper, aluminium, etc other than the concentric tube region which is stainless tubes in the design of the heat exchanger is because of its cheapness and for the fact that milk contains lactic acid which reacts with metals to form salt, thereby affecting the taste and flavour of the milk product.

3.3 Components of the Pasteurizer and Specifications:

The component of heat exchanger includes: Concentric tubes, pumps, Containers, Digital Temperature recorder, control panel, boiling ring, thermometer, rollers, ply-wood base and it frame and Sensors.

Plate 5: Front View of the Heat Exchanger-pastuerizer

3.4 Test Procedure

1. Sample of raw milk was collected as obtain in a bottle to the microbiology laboratory for examination of bacteria count.
2. Water reservoir was filled-up to obtain 40 litres of water and filled-up raw milk reservoir to obtain 40 litres of raw milk (for the first and second experiment, and 20 litres of raw milk third experiment).
3. Pump 1 was switched on and the gate valve opened to transfer water to the 50 litres water bucket and close the gate valve.
4. Pump 2 is switched on and the gate valve is opened to transfer raw milk to the 50 litres milk bucket and close the gate valve.
5. The two heater elements are switched on and the thermostat set to temperature of 90°C. Insert thermometer for temperature confirmation.
6. After the temperature of the water is read at 90°C, pump 3 is then switched on and the gate valve opened to start hot water circulation.
7. At the same time pump 4 is switched on and the gate valve opened to start raw milk circulation. Insert thermometer for pasteurization temperature confirmation.
8. The timer is then set at 30 minute so that the system automatically stops at 30 minutes.
9. The thermometer for pasteurization temperature is then checked.
10. Final sample of 63°C pasteurization temperature is obtained to the microbiology laboratory for examination of bacteria count.

3.5 Maintenance and Safety

1. The buckets can be removed for cleaning through the union connectors.
2. Hot water is passed through the concentric tube chambers continuously over a long period of time to ensure cleaning is correctly done.
3. The pumps can also be removed through the unions when repair is required.
4. All joints, unions and all components should be handled with care to ensure safety of the system.
5. The laid down procedure of operations must be strictly adhered, to avoid failure.

3.6 Governing Equations

For designing or predicting the performance of a heat exchanger, it is necessary that the total heat transfer may be related to its governing parameters: (i) U (overall heat transfer coefficient) due to various modes of heat transfer (ii) A total surface area of the heat transfer and (iii) t_1, t_2 (the inlet and outlet fluid temperatures) Fig 3.1 shows the overall energy balance in a heat exchanger.

Let

M = Mass flow rate, kg/s

Cp = Specific heat of fluid of constant pressure, J/kgK

T = Temperature of fluid ^{0}C and

Δt = Temperature drop or rise of a fluid across the heat exchanger.

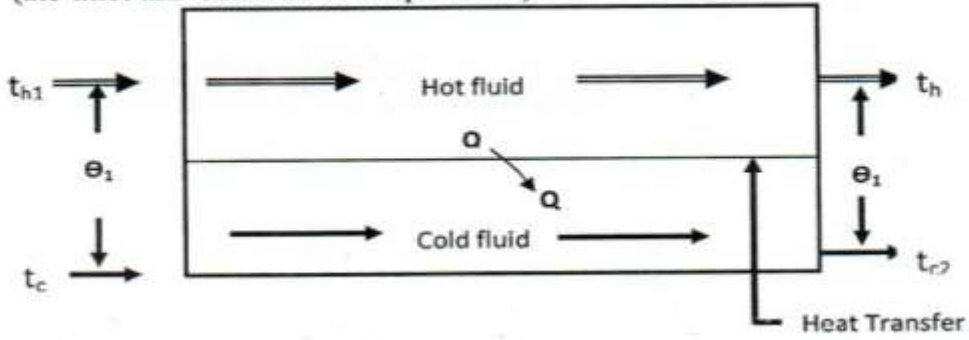

Figure 6: Overall energy balance in heat exchanger.

Subscript h and c refer to the hot and cold fluid respectively; subscript 1 and 2 correspond to the inlet and outlet conditions respectively.

Assuming that there is no heat loss to the surroundings and potential and kinetic energy charges are negligible, from the energy balance in a heat exchanger, we have;

Heat given up by the hot fluid

$$Q = M_h C_{ph}(t_{h1} - t_{h2}) \tag*{1}$$

Heat picked up by the cold fluid

$$Q = M_c C_{pc}(t_{c1} - t_{c2}) \tag*{2}$$

Total heat transfer rate in the heat exchanger.

$$Q = UA\theta_m \tag*{3}$$

Where

U = Overall heat transfer coefficient between the two fluids

A = Effective heat transfer area and

θm = Appropriate mean value of temperature difference or logarithmic mean temperature difference (LMTD) (Rajput, 2006).

Summary of governing equations include;

$$Q = UA \cdot \theta_m$$

$$\theta_m = \frac{\theta_2 - \theta_1}{\mathrm{In}\left(\theta_2/\theta_1\right)} = \frac{\theta_1 - \theta_2}{\mathrm{In}\left(\theta_2/\theta_1\right)}$$

With respect to temperature notations as ΔT_m, we have;

$$Q = UA \cdot \Delta T_m$$

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\mathrm{In}(\Delta T_1/\Delta T_2)} \quad 4$$

Evaluation of ΔT_1 and ΔT_2 depends on the heat exchanger type.

Consider figures below,

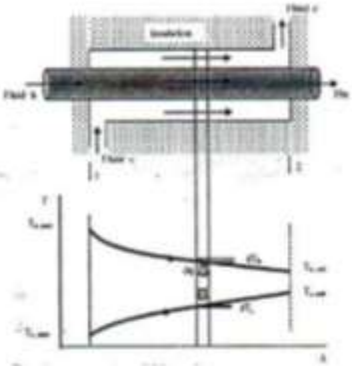

Figure 8: A co-current (or parallel) heat exchanger

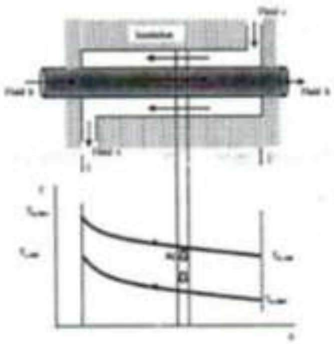

Figure 9: A counter current (or counter flow) heat exchanger

For both Parallel and Counter Flow Heat Exchanger

$T_{h,\ inlet} = T_{h1};$ $\quad T_{c,\ inlet} = T_{c1}$

$T_{h,\ exit} = T_{h2};$ $\quad T_{c,\ exit} = T_{c2}$

Hence, $\Delta T_1 = T_{h1} - T_{c1}$ $\quad \Delta T_2 = T_{h2} - T_{c2}$ (Cengel Y. A. *et* al, 2001)

3.7 Thermal Design Principle of Cycle Pasteurization

The aim of the process of cycle pasteurization is to use recycled heat transfer technique over a short concentric tube, to constrain the heat transfer area of plates and conventional long arranged or floating tubes to a reduced size in terms of cycles/minute.

The specifications used for thermal calculations of the heat exchanger are as follows:

i. Thermal conductivity of stainless steel tube
ii. Specific heat of the milk Cp_c
iii. Specific heat of water Cp_w
iv. Heat Transfer Coefficient on the milk side
v. Heat Transfer Coefficient on the water side
vi. Mass flow rate of milk $\dot{m}_c$
vii. Mass flow rate of water $\dot{m}_w$

Heat gained by the milk

$$Q_c = m_c cp_c(t_{c2} - tc_1) \qquad 5$$

Heat lost by water

$$Q_h = m_h cp_h(t_{h1} - t_{h2}) \qquad 6$$

But

$$Heat\ lost\ by\ water\ = Heat\ gained\ by\ the\ milk$$

Also, since the heat exchanger is adiabatic and temperature controlled at 63^{0}C pasteurization temperature.

$$Heat\ gained\ by\ the\ milk = Heat\ tranfer\ to\ the\ milk$$

This implies that; $Q_h = Q_c = Q = U_l \times \Delta T_m \times A_l$ 7

i.e if, $Q_c = Q_h$

$t_{h2} =?$ Can then be calculated.

$$U_l = \frac{1}{R_t}$$

8

For Counter Current Flows;

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$$A_l = \frac{Q}{U_l \times \Delta T_m}$$

$A = 2\pi r l \rightarrow l = \frac{A}{2\pi r}$

$Total\ length\ required =?$

$$No\ of\ cycles = \frac{Total\ length\ required}{Reduced\ length}$$

9

In terms of Cycles/minutes,

$$= \frac{No\ of\ cycles}{Minutes\ of\ Experiment}$$

$$\approx cycles/minute$$

$$\text{Effectiveness} = \frac{Actual\ heat\ transfer}{maximum\ possible\ heat\ transfer}$$

$$\varepsilon = \frac{Q}{Q_{max}}$$

$$c_h = \dot{m}_h cp_h$$

$$c_c = \dot{m}_c cp_c$$

$$c_h > c_c \qquad \varepsilon = \frac{c_c(t_{c2} - t_{c1})}{c_{min}(t_{h2} - t_{h1})} \qquad 10$$

3.8 Thermal Calculation of the Heat Exchanger Experiment

The specifications used are;

(i) Thermal Conductivity of stainless steel tube = 60W/mk

(ii) Specific heat of the milk C_{Pc} = 3.9 kj/kg^{0}C = 3,900 J/kgk.

(iii) Specific heat of the water C_{Ph} = 4.18 kj/kg^{0}c = 4,180J/kgk.

(iv) Heat Transfer coefficient on the milk side = 500 W/m^{2}k

(v) Heat Transfer coefficient on the water side = 900 W/m^{2}k

The dimensions measured are;

(i) Mass flow rate of milk $\dot{m}_c$ = 0.61kg/s

(ii) Mass flow rate of water $\dot{m}_w$ = 0.69kg/s

At the time the timer switch off the water pumps the temperature of the pasteurized milk was 57^{0}c.

(iii) The thermostat of the water heats was set at 87°C, 90°C and the water temperature heated was confirmed by the thermometer.

(iv) Therefore water enters the heat exchanger at 87^0 c and 90°C.
(v) Inside diameter of the inner tube = 12.7mm = 0.0127m,
(vi) Thickness of the inner tube = 1mm = 0.001m

(vii) Inside diameter of the outer tube =1' = 25.4mm 2 0.0254m.

(viii) thickness of the outer tube = 1.5mm = 0,0015m.

The summary of the experiments are:

(a) Using 40 liters of water and 40 liters of raw milk.

- Water temperature = 87°C
- Temperature of pasteurized milk obtained at 30 minutes = 57°C

(b) Using 40 liters of water and 40 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 60°C

(c) Using 40 liters of water and 35 litres of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 62°C

(d) Using 40 liters of water and 30 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 63°C

(e) Using 40 liters of water and 25 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 63°C

(f) Using 40 liters of water and 20 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 63°C

(g) Using 40 liters of water and 15 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 64°C

(h) Using 40 liters of water and 10 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 66°C

(i) Using 40 liters of water and 5 liters of raw milk

- Water temperature = 90°C
- Temperature of pasteurized milk obtained at 30 minutes = 67°C

3.8.1 Calculations for Experiment (a)

Using 40 liters of water and 40 liters of raw milk.

Step 1: For Counter Flow

Heat gained by the milk

$$Q_c = m_c C_{pc}(t_{c2} - t_{c1})$$
$$= 0.61 \times 3900 \times (57 - 27)$$
$$= 71,370 \text{ W}\underline{\text{ATTS}}$$

Heat lost by water

$$Q_c = m_h C_{ph}(t_{h2} - t_{h1})$$
$$= 0.69 \times 4180 \times (t_{h2} - 87)$$
$$= 2884.2 \times (t_{h2} - 87)$$

But

$$heat\ gained\ by\ milk = heat\ lost\ by\ water$$

i.e $Q_c = Q_h$

$$71370 = 2884.2 \times (t_{h2} - 87)$$
$$t_{h2} - 87 = {}^{71370}/_{2884.2}$$
$$t_{h2} - 87 = 24.745$$
$$t_{h2} = 62.25°\text{C}$$

Step 2

Let us base the U calculations on the inner area of the inside tube. As the length of the tube is not known. We can base this calculation for a 1m long.

Here 0.0127 and 0.00635 are the outer and inner radii of the inside tube.

$$U_i = \frac{1}{R_t} = \frac{1}{\frac{1}{h_i A_i} + \frac{\ln(R_O/R_i)}{2\pi k L} + \frac{1}{h_O A_O}}$$

$$U_i = \frac{1}{R_t} = \frac{1}{\pi \times 0.0127} \times \left(\frac{1}{\frac{1}{500 \times 0.0127\pi} + \frac{\ln(0.0127/0.0063)}{2\pi \times 60} + \frac{1}{900 \times 0.0127\pi}}\right)$$
$$= 25.064 \times \left(\frac{1}{\frac{1}{19.95} + \frac{0.693}{376.99} + \frac{1}{71.82}}\right)$$
$$= 25.064 \times \left(\frac{1}{0.05 + 1.838 \times 10^{-3} + 0.0139}\right)$$
$$= 25.064 \times \left(\frac{1}{0.065738}\right) = 25.064 \times 15.21190$$
$$= 381.27 w/m^2 k$$

Step 3: For counter current flow:

$$\Delta T_m = \frac{(87-57)-(62.25-27)}{\ln^{(87-57)}/_{(62.25-27)}} = \frac{30-35.25}{\ln(^{30}/_{35.25})}$$

$$= \frac{-5.25}{\ln 0.9022} = \frac{-5.25}{-0.102857} = 51.04°\mathrm{C}$$

$$Ai = \frac{Q}{U_i \times \Delta T_m} = \frac{71.370}{381.27 \times 51{,}04} = \frac{71.370}{19460.028} = 3.668m^2$$

Therefore

$$\text{Length} = \frac{3.668}{\pi \times 0.0127} = 91.92m$$

$$No\ of\ Cycles = \frac{91.92}{1.4} = 65.66$$

$$\approx 66 \text{ cycles}$$

In terms of seconds

$$= {}^{66}/_{60} = 1.1 \text{ cycles}$$

$$= 1 \text{ cycler per second}$$

3.8.2 Calculation for experiment (b)

Using 40 liters of water and 40 liters of raw milk

For counter flow

Heat gained by the milk

$$Q_c = m_c C_{pc}(t_{c2} - t_{c1})$$

$$= 0.61 \times 3900 \times (60 - 27)$$

$$= 78{,}507\mathrm{KJ/s}$$

Heat lost by water

$$Q_c = m_h C_{ph}(t_{h2} - t_{h1})$$

$$= 0.69 \times 4180 \times (t_{h2} - 90)$$

$$= 2884.2 \times (t_{h2} - 90)$$

But

$$heat\ gained\ by\ milk = heat\ gained\ by\ water$$

i.e $\quad Q_c = Q_h$

$$78507 = 2884.2 \times (t_{h2} - 90)$$

$$t_{h2} - 90 = {}^{78507}/_{2884.2}$$

$$t_{h2} - 90 = 27.2196$$

$$t_{h2} = 63°\text{C}$$

Step 2

Let us base the U calculations on the inner area of the inside tube. As the length of the tube is not known. We can base these calculations for a 1m long.

Here 0.0127 and 0.00635 are the outer and inner radii of the inside tube.

$$U_i = \frac{1}{R_t} = \frac{1}{\frac{1}{h_i A_i} + \frac{\ln(R_O/R_i)}{2\pi k L} + \frac{1}{h_O A_O}}$$

$$U_i = \frac{1}{R_t} = \frac{1}{\pi \times 0.0127} \times \left(\frac{1}{\frac{1}{500 \times 0.0127\pi} + \frac{\ln(0.0127/0.0063)}{2\pi \times 60} + \frac{1}{900 \times 0.0127\pi}} \right)$$

$$= 25.064 \times \left(\frac{1}{\frac{1}{19.95} + \frac{0.693}{376.99} + \frac{1}{71.82}} \right)$$

$$= 25.064 \times \left(\frac{1}{0.05 + 1.838 \times 10^{-3} + 0.0139} \right)$$

$$= 25.064 \times \left(\frac{1}{0.065738} \right) = 25.064 \times 15.21190$$

$$= 381.27 w/m^2 k$$

Step 3: For counter current flow:

$$\Delta T_m = \frac{(90 - 63) - (60 - 27)}{\ln {}^{(90 - 57)}/_{(60 - 27)}} = \frac{27 - 33}{\ln({}^{30}/_{36})}$$

$$= \frac{-6}{-0.182} = 32.91°\text{C}$$

$$Ai = \frac{Q}{U_i \times \Delta T_m} = \frac{78507}{381.27 \times 32.91} = \frac{78507}{12547.5957} = 6.256 m^2$$

Therefore

$$\text{Length} = \frac{6.256}{\pi \times 0.0127} = 156.79 m$$

$$No\ of\ Cycles = \frac{156.79}{1.4} = 111.999$$

$$\approx 112\ cycles$$

In terms of seconds

$$= {}^{112}/_{60} = 1.86 \text{ cycles}$$

$$= 2 \text{ cycler per second}$$

3.8.3 Calculation for experiment (f)

Using 40 liters of water and 20 liters of raw milk

For counter flow

Heat gained by the milk

$$Q_c = m_c C_{pc}(t_{c2} - t_{c1})$$

$$= 0.61 \times 3900 \times (63 - 27)$$

$$= 85{,}644 \text{KJ/s}$$

Heat lost by water

$$Q_c = m_h C_{ph}(t_{h2} - t_{h1})$$

$$= 0.69 \times 4180 \times (t_{h2} - 90)$$

$$= 2884.2 \times (t_{h2} - 90)$$

But

$$heat\ gained\ by\ milk = heat\ gained\ by\ water$$

i.e $\quad Q_c = Q_h$

$$85644 = 2884.2 \times (t_{h2} - 90)$$

$$t_{h2} - 90 = {}^{85644}/_{2884.2}$$

$$t_{h2} - 90 = 29.694$$

$$t_{h2} = 60.31°\text{C}$$

Step 2

Let us base the U calculations on the inner area of the inside tube. As the length of the tube is not known. We can base this calculations for a 1m long.

Here 0.0127 and 0.00635 are the outer and inner radii of the inside tube.

$$U_i = \frac{1}{R_t} = \frac{1}{\frac{1}{h_i A_i} + \frac{\ln(R_O/R_i)}{2\pi k L} + \frac{1}{h_O A_O}}$$

$$U_i \quad = \frac{1}{R_t} = \frac{1}{\pi \times 0.0127} \times \left(\frac{1}{\frac{1}{500 \times 0.0127\pi} + \frac{\ln(0.0127/0.0063)}{2\pi \times 60} + \frac{1}{900 \times 0.0127\pi}} \right)$$

$$= 25.064 \times \left(\frac{1}{\frac{1}{19.95} + \frac{0.693}{376.99} + \frac{1}{71.82}} \right)$$

$$= 25.064 \times \left(\frac{1}{0.05 + 1.838 \times 10^{-3} + 0.0139} \right)$$

$$= 25.064 \times \left(\frac{1}{0.065738} \right) = 25.064 \times 15.21190$$

$$= 381.27 w/m^2 k$$

Step 3: For counter current flow:

$$\Delta T_m \quad = \frac{(90 - 60.31) - (63 - 27)}{\ln {}^{(90 - 60.31)}\!/_{(63 - 27)}} = \frac{29.69 - 36}{\ln({}^{27}\!/_{33.31})}$$

$$= \frac{-6.31}{-0.21} = 30.05°\text{C}$$

$$Ai \quad = \frac{Q}{U_i \times \Delta T_m} = \frac{85644}{381.27 \times 30.05} = \frac{85644}{11457.16} = 7.475m^2$$

Therefore

$$\text{Length} = \frac{7.475}{\pi \times 0.0127} = 187.35m$$

$$No\ of\ Cycles \ = \frac{187.35}{1.4} = 133.821$$

$$\approx 134\ cycles$$

In terms of seconds

$$= {}^{134}\!/_{60} = 2.33 \text{ cycles}$$

$$\approx 2 \text{ cycles per second.}$$

3.9 Effectiveness of the Heat Exchanger

3.9.1 Calculations for Experiment (a)

Using 40 liters of water and 40 liters of raw milk

$$\varepsilon = \frac{Actual\ heat\ transfer}{Maximum\ possible\ heat\ transfer} = \frac{Q}{Q_{max}}$$

$$\varepsilon = \frac{C_h(t_{h1} - t_{h2})}{C_{min}(t_{h1} - t_{c1})} = \frac{C_c(t_{c1} - t_{c2})}{C_{min}(t_{h1} - t_{c1})}$$

$$C_h = m_h C_{ph} h_h$$

$$= 0.69 \times 4180 = 2884.2 \qquad \text{C} - \text{Max}$$

$$C_c = m_c C_{pc} h_c$$

$$= 0.61 \times 3900 = 2379 \qquad \text{C – Min}$$

Hence

$$C_h > C_c$$

$$\varepsilon = \frac{2884.2\,(87-62.25)}{2379\,(87-27)} = \frac{71383.95}{142740} = 0.5000977 \qquad \approx 0.50$$

3.9.2 Calculation for experiment (b)

Using 40 liters of water and 40 liters of raw milk

$$\varepsilon = \frac{Actual\ heat\ transfer}{Maximum\ possible\ heat\ transfer} = \frac{Q}{Q_{max}}$$

$$\varepsilon = \frac{C_h(t_{h1}-t_{h2})}{C_{min}(t_{h1}-t_{c1})} = \frac{C_c(t_{c1}-t_{c2})}{C_{min}(t_{h1}-t_{c1})}$$

$$C_h = m_h C_{ph} h_h$$

$$= 0.69 \times 4180 = 2884.2 \qquad \text{C – Max}$$

$$C_c = m_c C_{pc} h_c$$

$$= 0.61 \times 3900 = 2379 \qquad \text{C – Min}$$

Hence

$$C_h > C_c$$

$$\varepsilon = \frac{2884.2\,(90-63)}{2379\,(90-27)} = \frac{77873.4}{149877} = 0.519582057$$

$$\approx 0.52$$

3.9.3 Calculation for experiment (f)

Using 40 liters of water and 20 liters of raw milk

$$\varepsilon = \frac{Actual\ heat\ transfer}{Maximum\ possible\ heat\ transfer} = \frac{Q}{Q_{max}}$$

$$\varepsilon = \frac{C_h(t_{h1}-t_{h2})}{C_{min}(t_{h1}-t_{c1})} = \frac{C_c(t_{c1}-t_{c2})}{C_{min}(t_{h1}-t_{c1})}$$

$$C_h = m_h C_{ph} h_h$$

$$= 0.69 \times 4180 = 2884.2 \qquad \text{C – Max}$$

$$C_c = m_c C_{pc} h_c$$

$$= 0.61 \times 3900 = 2379 \qquad \text{C} - \text{Min}$$

Hence

$$C_h > C_c$$

$$\varepsilon = \frac{2884.2\,(90-60.31)}{2379\,(90-27)} = \frac{85631.89}{149877} = 0.57134777 \approx 0.6$$

4.0 RESULTS:

Samples of raw milk collected were passed through the heat transfer area (concentric pipe) with hot water. Ten (10) different experiments were carried out as volumes of raw milk were varied along. At the end of 30 minutes of each experiment, pasteurization temperatures were recorded with the aid of thermometer insert. Thermal calculation method was then used to obtain other required results. Among the result obtained, reference or emphasis is given to experiments (a), (b) and (f) which provides good explanations for carrying out the experiments. The results are presented below in graphs and tables.

Experiment (a),

- 91.92m concentric tube length of pipe required.
- 66cycles/1cycle per second and 0.50 heat exchange effectiveness obtained.

Experiment (b)

- 156.79m concentric tube length of pipe required.
- 112cycles/2cycles per second and 0.52 heat exchange effectiveness obtained.

Experiment (f)

- 187.35m concentric tube length of pipe required.
- 134cycles/3cycles per second and 0.60 heat exchange effectiveness obtained

4.1 Graphical Representation of Heat Transfer Processes

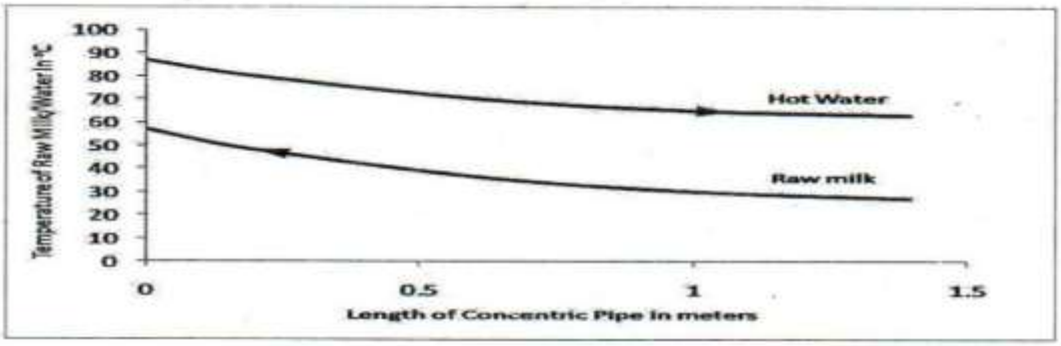

Fig. 4.1 Graph of Experiment (a): Temperature of water/raw milk in °C against Length of Concentric Pipe in meters.

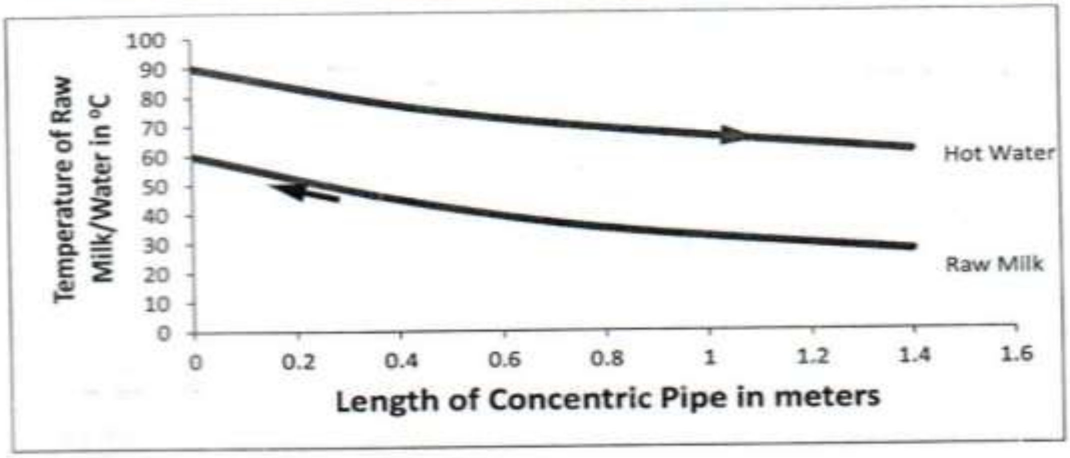

Fig. 4.2 Graph of Experiment (b): Temperature of water/raw milk in °C against Length of Concentric Pipe in meters.

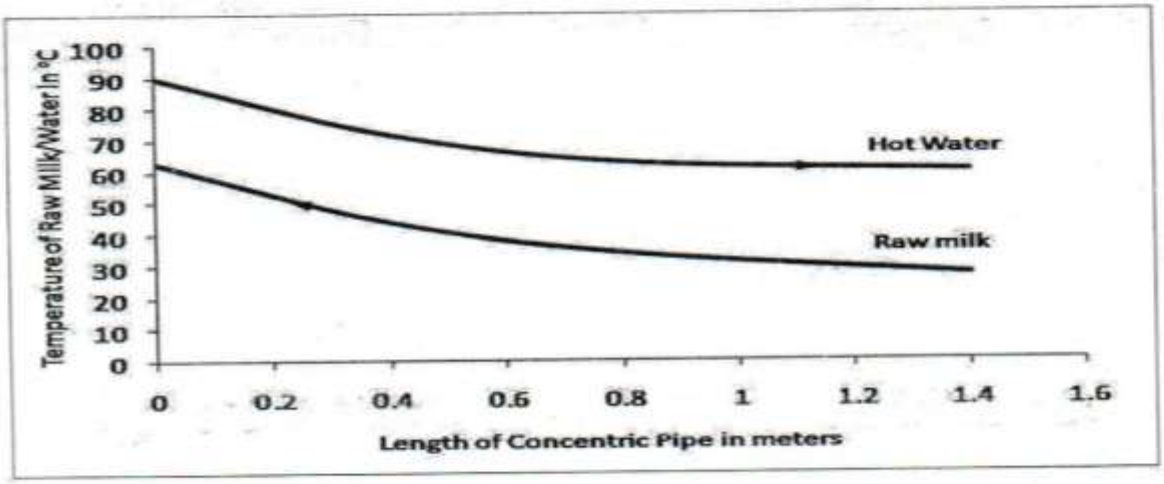

Fig. 4.3 Graph of Experiment (f): Temperature of water/raw milk in °C against Length of Concentric Pipe in meters.

4.2 Experimental Temperature Readings

Table 4.1 Ratio of hot water/raw milk volumes used with temperature readings recorded after 30 minutes heat exchange.

Volume: Hot water/Raw Milk	**40/40**	**40/40**	**40/35**	**40/30**	**40/25**	**40/20**	**40/15**	**40/10**	**40/05**

Hot water temperature used	87°C	90°C	90°C	90°C	90°C	90°C	90°C	90°C	90°C
Temperature of raw milk after 30 minutes heat exchange	57°C	60°C	62°C	63°C	63°C	63°C	64°C	66°C	67°C
Temperature of water after 30minutes heat exchange	63°C	62°C	61°C	60°C	60°C	60°C	59°C	58°C	57°C
Initial Raw milk Temperature	27°C	27°C	27°C	27°C	27°C	27°C	27°C	27°C	27°C

4.3 Experimental Temperature Readings

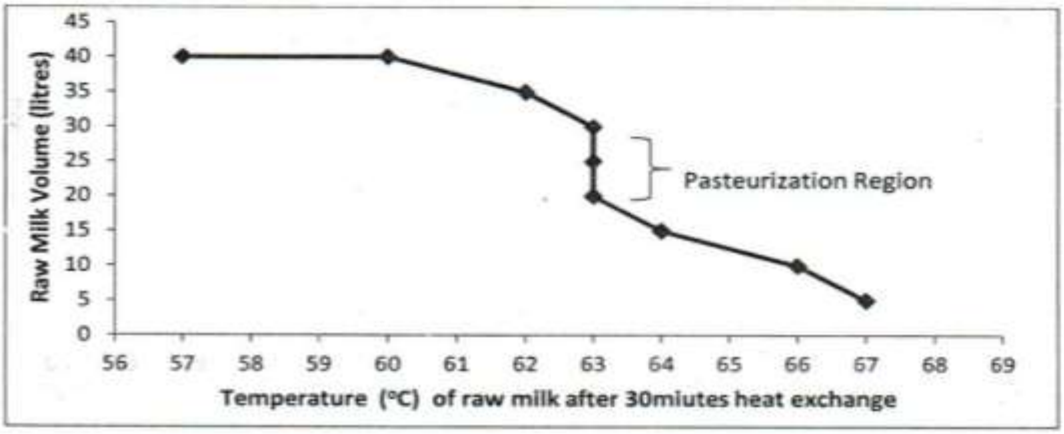

Fig. 4.4 Raw milk volumes in litres against the temperature readings in °C.

4.4 Microbiological Analysis of Milk

Table 4.2 Results of microbiological analysis of the milk in comparison with US standard

S/N	Parameters	Raw Milk (cfu/ml)	US Standard Compared (cfu/ml)	Pasteurized Milk at 63°C 30liters Vol. (cfu/ml)	Pasteurized Milk at 63°C 25liters Vol. (cfu/ml)	Pasteurized Milk at 63°C 20liters Vol. (cfu/ml)	US Standard Compared (cfu/ml)	Pasteurized Milk at 64°C 25liters Vol. (cfu/ml)	Pasteurized Milk at 62°C 20liters Vol. (cfu/ml)
1.	Total Bacteria Count	96×10^3	100×10^3	19×10^3	15×10^3	11×10^3	0 to 20×10^3	-2×10^3	22×10^3
2.	Total Coliform Count	17.8×10^3	20×10^3	0.009×10^3	0.007×10^3	0.004×10^3	0 to 0.01×10^3	-0.002×10^3	0.02×10^3
3.	Total Feacal Coliform Count	8.0×10^3	10×10^3	0.003×10^3	0.002×10^3	0.001×10^3	0 to 0.005×10^3	-0.001×10^3	0.01×10^3

cfu/ml = colony forming unity per ml

5.0 DISCUSSION OF RESULTS AND CONCLUSION

5.1 DISCUSSION OF RESULTS

The log-mean temperature difference method used for the heat transfer analysis produced similar results from the experiments. Thus, presentation of the results make reference to only experiment (a), (b) and (f) for ease of discussions.

From the results obtained, to construct 91.92m, 156.79m and 187.35m concentric tube length of pipe in each experimental reference case, would not have an economy of space and cost. Thus, the system was designed to recycle the heat exchange process. Hence, neglecting other areas and considering heat transfer area of 1.4m length of pipe, we have 66, 112 and 134 cycles respectively. The higher the number of cycles or cycles per second the better the heat transfer effectiveness. The most effective pasteurization result was then obtained in experiment (f).

Thermal calculations methods of heat exchange process was used to obtain heat gained by milk and heat lost by water after pasteurization period of 30 minutes in each experimental case as shown in table 4.1

The graphs presented in figure 4.1, 4.2 and 4.3 shows that for water, the curve slopes downward over the length of concentric tube pipe indicating that water losses heat from 87°C, 90°C and 90°C to 63°C, 62°C and 60°C in experiment (a), (b) and (f) respectively. Similarly, for raw milk, the curve slopes upward over the length of concentric tube pipe indicating that raw milk gains heat from 27°C at each case to 57°C, 60°C and 63°C in experiment (a), (b) and (f) respectively.

The graph in figure 4.4 indicates that at 40 liters volume in experiment (a) and (b), pasteurization of raw milk at 57°C and 60°C were obtained. The experiment (f) gave 63°C pasteurization for 20 liters volume of raw milk used. This can be seen in the pasteurization region. The principal aim of the experiment is to obtain pasteurization of raw milk at 63°C in 30 minutes.

The first experiment used 40 liters of water and 40 liters of raw milk, heat exchange with hot water temperature of 87°C to obtain pasteurization temperature of 57°C. The effectiveness of heat the exchange obtained was 0.5. The targeted result has not been met.

The second experiment used 40 liters of water and 40 liters of raw milk, heat exchange with hot water temperature of 90°C, a pasteurization temperature of 60°C was obtaid. The effectiveness of the heat exchange was 0.52. The targeted result has not yet been met.

The experiment which uses 40 liters of water and 30, 25, and 20 liters of raw milk was used to exchange heat with hot water temperature of 90°C, 63°C was obtained. The effectiveness of the heat exchange rose approximately to 0.6 for more than optimum effectiveness.

The volumes of raw milk within the pasteurization region gave a total bacterial count of 19 x 10^3cfu/ml, 15 x 10^3cfu/ml and 11 x 10^3cfu/ml respectively. This is a drastic reduction of total bacterial count from the initial value of 96x10^3cfu/ml recorded of the raw milk. Generally, microbiological analysis after pasteurization a significant reduction in the total bacteria count, total coli form count and total fecal coli form count within pasteurization region in comparison with US standard as shown in table 4.2.

CONCLUSION

In the field of engineering, transfer processes are very important such as is encountered in the process of pasteurization. The 63°C pasteurization for 30 minutes and the total head loss of both water and milk side of the Heat Exchanger will be so negligible The concentric tube heat exchanger of this kind will make fouling of the milk eliminated without stirring the system. The bacteriological result expected to be obtained will be a

Published on AU J.T. 13(2): 128-133.

Frank Kreith, P.E and Jan F. Kreider, P.E., (1978). *Principle of Thermodynamics and Heat Transfer Applied to Solar Energy.* Third Edition,

Incropera, F.P. and DeWiitt, D.P. (2002). *Fundamentals of Heat and Mass Transfer*, Fourth Edition, John Wiley and Sons, pp.143-165.

Parrot, J.E. (1978). Theoretical Upper Limited to Conversion Efficiency of Solar Energy, pp. 43-56

Lienhard, J.H., (2005). *A Heat Transfer Textbook,* Prentice – Hall

Noppawwan U. (2005). Efficiency of Pasteurization process and Shelf life on Bacteriological Quality of Milk. MSc Thesis, Mahidol University, pp. 22-57.

Bertu, W. J. Dapar, M. Gusi, A.M. Ngulukun, S.S. Leo, S. and Jwander L.D. (2010). Prevalence of brucella antibodies in marketed milk in Jos and environs, African Journal and food science Vol. 4(2) pp 062 – 064. (Berman 1981, Chuckwu 1987, Farrell 1996, Mnija 1999) Retrieved from http://:www.acadjourn.org/ajfs.

Yunus, A. Cengel and Robert, H. Turner, (2001). *Fundaments of Thermal – Fluids Sciences,* S.I. Unit Edition, McGraw Hill, New York, pp. 181 – 183, 881 – 928, 892 – 894.