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# Flow Simulation of Recycled Concentric Tube Heat Exchanger for Raw Milk Micro-Scale Pasteurization

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## Abstract

*Heat exchanger, a versatile equipment which finds its application in both industrial and domestic environment is simulated with the principle of recycled heat transfer technique over a short concentric tube. The simulation of the heat exchanger was to ascertain its viability of solving the problem of portability, cost effectiveness and micro-scale pasteurization of milk product. This new concept is a Short Tube-Low Temperature, Long Time Pasteurization (ST-LTLT) or Cycle Pasteurization. The simulation provided 62.88*$^{o}$C *and 61.12*$^{o}$C *average temperature of liquid and solid respectively on iterative programme or cycles/minutes which provided an obvious plat form for the feasibility of micro-scale pasteurization with cost-effectiveness and portability. The exhibited behavior of turbulent velocity, pressure drop and density were in conformity with theory of pasteurization. Indeed, this concept if successful will complement the existing conventional methods of arranging plates and long concentric pipes for High Temperature Short Time (HTST) and Low Temperature Long Time (LTLT) which is characterized with the challenge of micro-scale pasteurization. The study of transient heatanalysis of the heat exchanger to guide the design and construction process precedes this paper.*

**Keywords**: pasteurization, tube heat exchanger, cycle pasteurization

## 1. Introduction

The concentric tube heat exchangers have a simple design, being made of two concentric tubes, where a fluid flows through the interior tube, while the other one flows through the ring-type space. According to Lienhard[1], hot and cold fluids enters at the same end in the parallel flow arrangement, while in the counter flow arrangement, the fluids enter at opposite ends, flow in the opposite direction and leave at opposite ends. In counter flow, heat exchangers, leaving steams can approach the temperature of the entering stream of the other component and on this account counter flow exchangers are often preferred [2]. This types of heat exchanger is been used in various industrial domains, especially the food industry and oil refinery [3]. The concentric tube heat exchangers is applied as applied to milk pasteurization present advantages such as simple structure, operation in counter-flow, operation at relatively low flow rates to mention but few, but present relatively high cost due to several arrangement of pipes to obtain the desired heat transfer temperature [4].

To this end, the problem of cost-effectiveness and micro-scale pasteurization of milk has been the greatest challenge of the dairy industry world over. This challenge is more in Africa where poverty rate is high and individuals can not afford expensively pasteurized milk from the available few dairy industries. Thus, the continued intake of un-pasteurized milk across developing countries in Africa including Nigeria which possess series of hazard and life threatening situation through decrease such as Brucellosis with its acute phase progressing into gastro intestinal complication, respiratory complications, loss of pregnancy and poor breast feeding, etc. if un-treated the pattern waxes and wanes our several days and the patient may dies [5].It is therefore required that effort be made by African Indigenous research and technology in this direction. So as to improve on the quality of local milk consumption at affordable rate which are sold across the streets un-pasteurized as “fura da nono” with the believe that it is safe for consumption [6]. Saving many lives which are lost due to this contagious disease and making pasteurization of milk a moderator regulation before it consumptions in Africa.

Pasteurization as applied to milk means that the exposure of the products to a heat treatment which will destroy pathogenic organism and yet not alter the flavor or composition of product. Theguide line for milk pasteurization had been 75$^{o}$C for 15 seconds (High Temperature Short Time Pasteurization) and 63$^{o}$C for 30 minutes (Low Temperature Long Time Pasteurization). These two cases are the conventional of milk pasteurization which has large space occupation and are also expensive in construction.The phenomenon of Short-Tube –Low Temperature Long Time pasteurization (ST-LTLT) or cycle pasteurization is developed out of the need to provide space economy such that milk can be pasteurized on micro-scale bases with general cost effectiveness of the entire pasteurization process such that even at home milk can be pasteurized before consumption. The paper in question tends to use simulation as applicable to milk pasteurization from heat exchangers to bring out results equivalent to ones obtained from High Temperature Short Time Pasteurization (HTST) or Low Temperature Long Time Pasteurization (LTLT).In the new concept, heat transfer is measured in terms of cycles/minutes rather than total surface area or long arranged concentric tube in conventional Batch or flash pasteurization which is characterized with the problem of micro-scale pasteurization.

In other words, the aim of the paper is to simulate a short tube through a long temperature pasteurization process with recycle effect to provide cost effectives and micro-scale production of the pasteurized milk. The simulation of the design parameters at this stage will provides reference for optimization of operational options after construction. There are liability concerns over design decisions derived from simulation-based analyses and question regarding the credibility of results. Initiatives have to be put underway to address these barriers. Today, this ranges from creating user interfaces that are responsive to the iterative and evolving nature of the design process [7], to enable the use of simulation at the conceptual design state, to allowing simulation programmes to share data models with other tools such as CAD or solidworks drawing packages [7-9]. Thus, ASHRAE [10] demonstratedthat the integrity of simulation by design professional will continue to be a focus in the field conceiving of design for years to come.

The simulation result resolution will be a measure of the desired level accuracy of the results and as such will determine whether the conceived idea to achieve this aim will be feasible. Thus, providing us with a new technique named short tube-long temperature pasteurization or high temperature long time pasteurization e.g. 85$^{o}$c for 30minutes. Through, his position may be little oscillatory due to environmental condition [11].

## 1.1 The Heat Transfer Principle

The indirect heat transfer is the most commonly used method in dairies in it is been used for this study (Figure 1). In this method a partition is placed between the product and the heating or cooling medium. Heat is then transferred from the medium through the partition into the product.It means indirect heating rely on thermal conductivity to move the heat to the center or receiving medium.We assume that the heating medium is hot water, flowing on one side of the partition, and cold milk on the other. The partition is consequently heated on the heating-medium side and cooled on the product side. In a plate heat exchanger the plate is the partition. There is a boundary layer on each side of the partition. The velocity of the liquids is slowed down by friction to almost zero at the boundary layer in contact with the partition. The layer immediately outside the boundary layer is only slowed down by the liquid in the boundary layer and therefore has a low velocity. The velocity increases progressively, and is highest at the center of the channel. Factors influencing Design and performance evaluation of heat exchanger includes Permitted pressure drops, Viscosity of the liquids, Shape and thickness of the partition andpresence of fouling materials. In dimensioning the data for Heat Exchanger application, it is necessary to size and configure heat exchanger which depends on many factors.

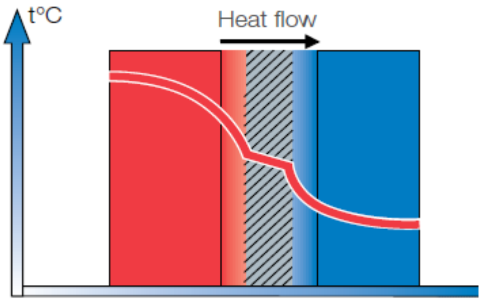


Figure 1.Heat flow between the heating medium and cold medium

## 2.Structure of Concentric Tube Heat Exchanger

The Figure2is a concentric tube heat exchanger, having flows in counter flow. The exchanger is characterized by four input values and two output values. The input variable are the following; $T_{h1}$, $\dot{m}_{hot}$ the input temperature and the mass flow rate of the hot fluid, $T_{c1}\dot{m}_{cold}$ – The input temperature and the mass flow rate of the cold fluid. The output variables are represented by $T_{h2}$ – the output temperature of the hot fluid and $T_{c2}$- the output temperature of the cold fluid.

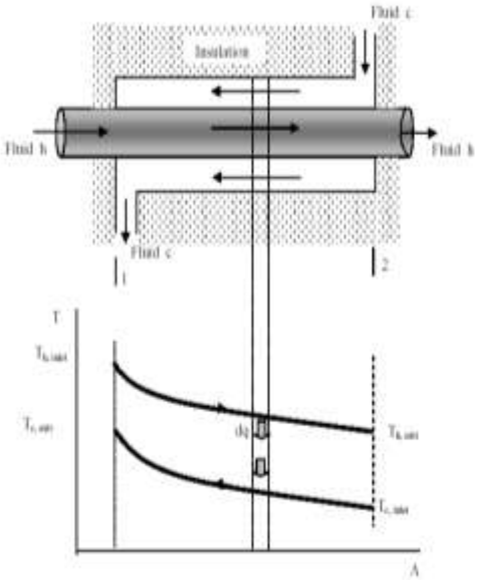


Figure 2: Concentric-tube heat exchanger construction

### 2.1 Concentric Tube Heat Exchanger Analysis

Considering the Figure 2 above, from our theoretical analysis, we obtain that;

$$Q = UA \cdot \theta_m \qquad \textbf{(1)}$$

$$\theta_m = \frac{\theta_2 - \theta_1}{\ln\left(\theta_2/\theta_1\right)} = \frac{\theta_1 - \theta_2}{\ln\left(\theta_2/\theta_1\right)} \qquad \textbf{(2)}$$

With respect to temperature notations as $\Delta T_m$, we have;

$$Q = UA \cdot \Delta T_m \qquad \textbf{(3)}$$

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \qquad \textbf{(4)}$$

**Where,**

$T_{h,\ inlet} = T_{h1}; T_{c,\ inlet} = T_{c1}$ ; $T_{h,\ exit} = T_{h2}; T_{c,\ exit} = T_{c2}$

Hence,

$$\Delta T_1 = T_{h1} - T_{c1} \qquad \textbf{(5)}$$

$$\Delta T_2 = T_{h2} - T_{c2} \qquad \textbf{(6)}$$

## 3. Methodology of Flow Simulation

The following steps were taken to achieve the desired flow simulation of the heat exchanger:The heat exchanger was sketched to specification in solid works.The project was then created in assembly mode using flow simulation wizard; consider the sketch,the fluid properties, units and dimensions as specified below. The computational domain for the sketch geometry and solid domains for each domain was created.The fluidsubdomains were inserted.The boundary conditions at inlet were specified as 90°C for the hot fluid (hot water) and 27°C for the cold fluid (cold milk. The target goals were specified as temperature, velocity, pressure, etc.

Table 1: Simulation Parameters

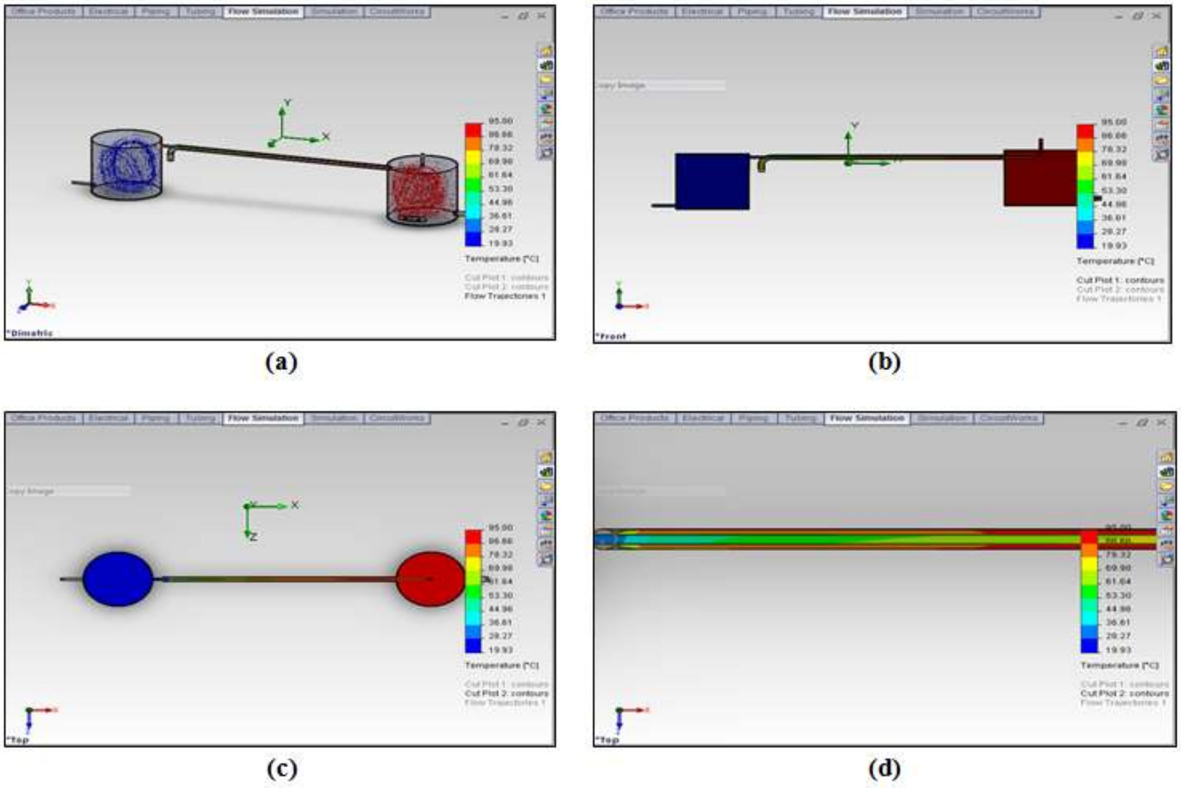
| **Quantity** | **Values** |
|---|---|
| Density of water | $1095 g/m^3$ |
| Density of milk | $1250 g/m^3$ |
| Diameter of pipe for water | $0.009375 m$ |
| Diameter of pipe for milk | 0.00625m |

| | |
|---|---|
| Dynamic viscosity of water | 0.0009 |
| Dynamic viscosity of milk | 0.003 |
| Thermal conductivity of stainless steel tube | 60W/m$^2$k |
| Specific heat of the milk | 3900J/kgK |
| Specific heat of water | 4200J/KgK |
| Heat Transfer Coefficient on the milk side | 500 W/m$^2$k |
| Heat Transfer Coefficient on the water side | 900 W/m$^2$k |
| Mass flow rate of milk | 0.0022Kg/s |
| Mass flow rate of water | 0.0043Kg/s |
| Highest Volume of liquid | 0.002m$^3$ |
| Electric heater | 1000watts |

## 4. Results and Discussion

### 4.1 Flow Simulation of the Concentric Heat Exchanger

As represented by stages flow simulation in Figure 3 (a, b c and d), it is a demonstration of how heat is been gradually transferred to the milk. Looking at the study area shown with x,y and z coordinates, the colour light blue is indicating a temperature of 28.27$^0$C from initial 27$^0$C which is read at the temperature placard. At the same time, the placard also shows how heat is been gradually lost by hot water from initial 90$^0$C to 86$^0$C. The heat exchange continuous, until the last coordinate in simulation h which shows that heat is gain by milk to 61.64$^0$C whereas water loses heat to 69.98$^0$C. The aftermath graphical representation shows results of temperature of solid with respect to time, temperature of fluid with respect to time, density with respect to time, velocity with time and pressure of fluids with respect to time.



(a) (b)

(c) (d)

Figure 3.Flow Simulation of the heat exchanger

### 4.2Iterations

The graph in Figure 4 shows that the temperature of solid surface rises steadily after the cycles/minute or iteration had moved passes the hydrodynamic entrance region to transfer heat to milk through thermal conductivity. The difference between the temperature of the solid surface and that of the milk will be as little as possible to show that essentially heat is been gained through it. This result also shows that the material of stainless steel chosen for the process heat transfer is a good solid material as the temperature of solid had actively rises above 60°C over iteration time of the experiment nearly what is required as the product temperature.Temperature of the liquid or product milk is the most essentially requirement of the pasteurization process. It is a comparative measure of what quantity of heat is received from the service or hot medium. Looking at the graph in Figure 5, the temperature steadily rises after cycles/minute moves beyond the hydrodynamic entry region during the heat transfer exhibiting the same pattern as temperature of the solid. This is quite a good result to show that heat is been gained or transferred from the service medium as required to keep the properties of the milk save. This also has shown that the path of heat transfer between the milk and hot water has provided internal thermodynamic equilibrium of the system as the measured temperature of the liquid is also above 62°C over iteration time or cycles/minute of the heat transfer. Essentially, satisfying that cycle pasteurization is a feasible idea.From the graph as shown below in Figure 6, as the heat transfer between the hot water and the cold milk increases or as the milk gain heat pass the hydrodynamic entrance region, the volumetric mass density of the milk decreases and becomes relatively constant along the remaining number of cycle/minute which essentially provides stable heat transfer to keep the required milk properties of milk safe for its consumption. In this situation, the heating of the milk by convection along the cycles/minute is made possible and kept constant to avoid over heating which provide a good feasibility for cycle pasteurization concept.

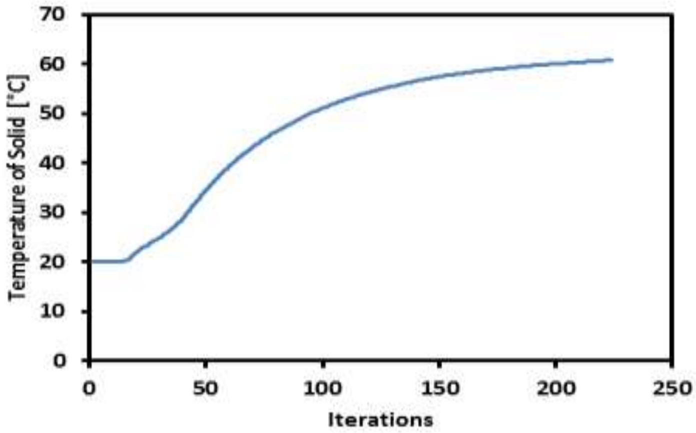


Figure 4.Temperature of Solid over time

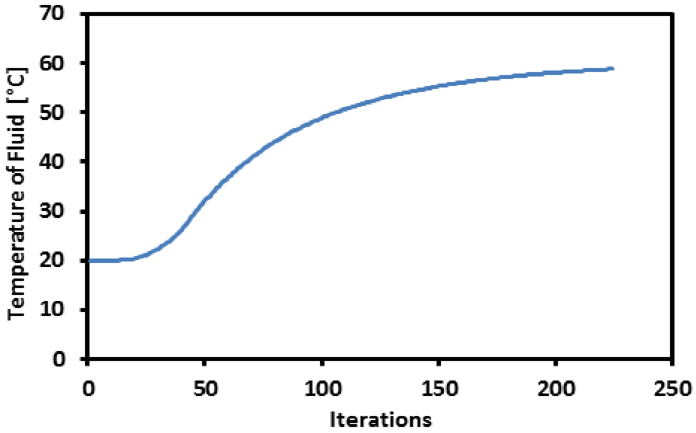


Figure 5.Temperature of fluid over time

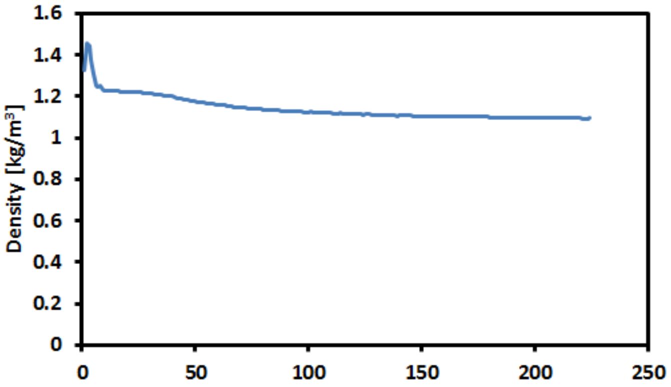


Figure 6 Density of fluid over time

### 4.3Velocity and Pressure

The graph in Figure 7 shows that as temperature increases, the velocity rises but becomes steady and uniform when the flow move passes the hydrodynamic entrance region. This is to provide

uniform heat transfer. The flow is also turbulent in nature because of the high Reynolds Number.
Essentially, throughout the length of pipe or number of cycles per minute, the behavior of velocity of the fluid or rate of change of position of both milk and water, equivalent to their speeds and direction of motion is as required to keep the milk nutritive values intact as it gains heat from the hot or service medium. In this case, the inertia forces dominate over the viscous forces which provides avenue for sufficient heat transfer to all particles of the fluid to prevent fouling.

It is required that for heat transfer to milk, only limited pressure drop is provided (Figure 8). The nature of force distributed over the area of heat transfer should be as optimal as possible. The higher pressure drop, the higher will be the rate of heat transfer. From the graph, the pressure is within its permitted limits over iterative time. Thus, the milk temperature gradually rises from 27$^{o}$C to 63$^{o}$C keeping its composited properties ultimately safe for consumption. Overall, as required the differential temperature between heating medium and product is as minimum as possible (62.88-61.12)$^{0}$C.

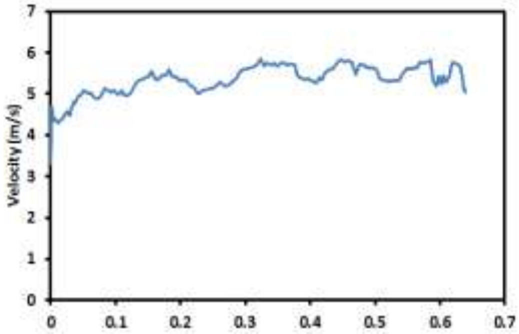


Figure 7.Velocity of fluid overthe length of pipe

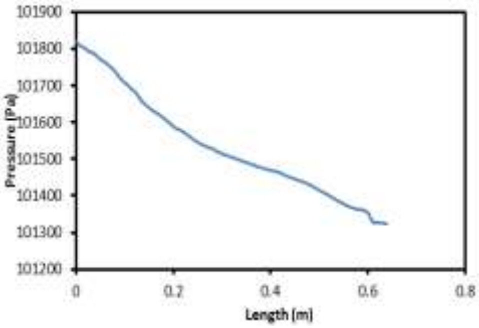


Figure 8.Pressure of fluid over the length of pipe

## 6. Conclusion

Since simulation mimics the practical aspect of a design, it becomes evident from the simulation results obtained that the model and design of the conceived idea of the proposed design is practically feasible. It is recommended that the design be fabricated for experimental test to ameliorate the challenges of local milk production in Africa.

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