MODELLING HEAT TRANSFER CHARACTERISTICS IN THE PASTEURIZATION PROCESS OF MEDIUM LONG NECKED BOTTLED BEERS

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ABSTRACT

Pasteurization is one of the most important steps in the preservation of beer products, which improves its shelf life by inactivating almost all the spoilage organisms present in it. However, there is no gain saying the fact that it is always difficult to determine the slowest heating zone, the temperature profile and pasteurization units inside bottled beer during pasteurization, hence there had been significant experimental and ANSYS fluent approaches on the problem. This work now developed Computational fluid dynamics model using COMSOL Multiphysics. The model was simulated to determine the slowest heating zone, temperature profile and pasteurization units inside the bottled beer during the pasteurization process. The results of the simulation were compared with the existing data in the literature. The results showed that, the location and size of the slowest heating zone is dependent on the time-temperature combination of each zone. The results also showed that the temperature profile of the bottled beer was found to be affected by the natural convection resulting from variation in density during pasteurization process and that the pasteurization unit increases with time subject to the temperature reached by the beer. Although the results of this work agreed with literatures in the aspects of slowest heating zone and temperature profiles, the results of pasteurization unit however did not agree. It was suspected that this must have been greatly affected by the bottle geometry, specific heat capacity and density of the beer in question. The work concludes that for effective pasteurization to be achieved, there is a need to optimize the spray water temperature and the time spent by the bottled product in each of the pasteurization zones.

Keywords: Keywords: Modeling, Heat transfer, Temperature profile, Pasteurization process, Bottled Beer**.**

INTRODUCTION

In recent years, there has been a significant increase in consumer interest in the quality and safety of food and that pasteurization plays an important role in the food manufacturing process (Marszałek et al., 2015 and Mao et al, 2011). Pasteurization is also a major step in food preservation, and is essential for ensuring safety of food products. It improves the shelf life of the product by effectively destroying almost all disease producing, and most other bacteria. Heat transfer studies in foods are of great importance since thermal processing is the most common technique used in pasteurization process (kiziltas et al, 2010). In the design of food pasteurization processes, process assessment-based mathematical analysis of the heat transfer within the food is of utmost importance to guarantee product safety (Denys et al, 2004). CFD is a simulation tool, which uses powerful computers in combination with applied mathematics to model fluid flow situations and aid in the optimal design of equipments and industrial processes and in recent years, a rapid development in the application of

CFD in food processing operations such as drying, sterilization, mixing, refrigeration and storage has been witnessed (Bhuvaneswari, and Anandharamakrishnan, 2014). Different experimental approaches and ANSYS fluent approaches have been carried out and also applied to gain insight to the heat transfer phenomenon in pasteurization. Kannan, and Gourisankar-Sandaka, 2008 carried out heat transfer analysis of a canned food in a still retort stand during sterilization using ANSYS Fluent where they investigated Nusselt number correlations on heat transfer characteristics in food cans with different aspect ratios and food medium thermal conductivities. They reported that the Nusselt numbers exhibited a sharp decrease with Time. They further noted that the Nusselt-Rayleigh (Nu–Ra) plot indicated branching at high Rayleigh numbers. The CFD has also been known to be useful in the analysis of beer pasteurization to determine the distribution of temperature and velocity profiles in the thermal pasteurization process and sterilization of canned food productions. Augusto et al., 2010 used ANSYS fluent-developed model to study the effect of orientation of canned beer during pasteurization. It was reported that package position did not result in process improvement. Bhuvaneswari, and Anandharamakrishnan, 2014 used ANSYS Fluent in heat transfer analysis of pasteurization of bottled beer in a tunnel pasteurizer. They reported that the resultant 15 to 30 PU value is adequate to achieve maximum sterility of beer. In general, literature appears scarce on the use of COMSOL Multi physics to model heat and mass transfer phenomenon of the pasteurization process of food products. In order to gain a better insight in to the power of COMSOL Multiphysics modeling of pasteurization process of food products, this work employed COMSOL Multiphysics to develop a computer-physical model to determine the slowest heating zone, temperature profile and pasteurization unit of a bottled beer in a 7 zone tunnel pasteurizer.

LITERATURE REVIEW

According to (Bhuvaneswari and Anandharamkrishnan, 2014), fermented beverages have a unique place in most societies because of their economic and cultural importance.

A widely applied and effective method for the extension of shelf-life of beverages in containers such as glass bottles is heat treatment in tunnel pasteurization plants, where the heat required to reduce the viability of contaminating organisms is applied by rinsing or spraying the containers with water (Horn et al, 1997).

Simulation studies of a pasteurization process based on finite element discretization of the Navier-Stokes equations observing a fluctuation in the initial phase of the heating due to recirculation eddies especially in the middle part of the bottle as reported in (Horn et al, 1997) which was in good agreement with the experimental observations in studies already conducted.

Determination of shelf life of beer

(Vanderhaegen et al, 2006) proposed that the shelf-life of beer is mostly determined by its microbiological, colloidal, foam, colour and flavor stabilities. The stability of the final product through several months can be achieved if common contaminants of beer such as Pediococcus ssp., Lactobacillus spp., and wild yeast like Saccharomyces spp., Hansenula, Dekkera, Brettanomyces, Candida and Pichia are inactivated (Priest and Stewart, 2006) and it has been observed that this organisms can be inactivated at time-temperature combination of around 20 minutes (1200 seconds) for 60^0C (Briggs et al, 2004)

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Cost of beer pasteurization

According to (Dilay, 2005) through the decades, the economic and environmental cost of energy has been steadily increasing. Such growth makes fuel usage and energy efficiency important. (Dilay, 2005) also explains that in a brewery the cost of electric energy and fuels comprises (20-30%) of production costs in the two stages of bottled beer production, namely; Grain processing i.e., unit operation such as clarification, milling, fermentation and filtration and Beer packaging which includes all operations undergone by the glass bottle, from its receiving washing, filling up and pasteurization to its secondary packaging and transportation. This makes the design of energy efficient tunnel pasteurization a very relevant matter, which stands to cause a significant cost reduction in pasteurization of beer in the world.

Limitations of beer pasteurization studies

According to (M-Walking-Ribeiro et al, 2011), the prevalent methods used for beer pasteurization is the thermal pasteurization, which provides great stability but also causes degradation of the sensory product quality due to extensive heat exposure. However the studies on non-thermal beer pasteurization have been limited to high hydrostatic pressure, ultra violet radiation and pulsed electric fields processing.

Though models have been developed to address this deficiencies by incorporating expressions for the pasteurization effect and the sensory deterioration due to heat treatment into the model equation as acclaimed in (Horn et al,1997). The complexity of the model, however make it difficult to be employed in the context of the simulation of a complete tunnel pasteurizer

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Degree of heat treatment

The final quality of the product depends upon the amount of heat it has received. The degree of heat treatment is represented by pasteurization unit (PU). The degree of heat treatment or pasteurization effect is expressed is expressed in terms of Pasteurization Units (PU). PU is defined as the effect achieved through one minute of heating at 60^0C. According to (Horn et al, 1997) studies of Del Vecchio beer spoilage organisms form the basis of this definition which can be written as;

$$PU = t\,10^{\frac{T-T_{ref}}{z}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1.1)$$

or expressed as a rate;

$$\frac{d\,PU}{dt} = 10^{\frac{T-T_{ref}}{z}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1.2)$$

with $T_{ref} = 60^oC$ and z = 6.94K.

Discoveries made through research.

A parametric analysis in a tunnel pasteurizer by (Dilay et al, 2006) it was discovered that the water pumping power may be reduced in about 50% (150KW) if the pipe diameter is increased from 150 to 200mm and heat transfer rater supplied to the tunnel may be reduced in 9.73% (5.4KW) with the use of a mineral wool-insulation layer 200mm thick. Although a thermo-economic viability study is suggested before introducing these design modifications on the tunnel. Also it was also observed that the zone 2 and 3 have little influence on the total power consumption in 8 zone tunnel pasteurizer.

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METHODOLOGY

The tunnel pasteurization of a bottled beer is selected for the purpose of this research, due its current industrial relevance.

Simulation

Bottle geometry in 2D axis-symmetrical was created using COMSOL Multiphysics. The geometrical structure of beer bottle is shown in fig 1. The geometry consists of four volumes, with the first volume representing the glass bottle with a height of 21.15 cm, and 4 mm thickness. The second volume represented the beer in the bottom portion of bottle with a height of 17.8 cm, the third volume represented the headspace with a height of 4.3cm. The fourth volume represents the metal cap of 0.5 mm thickness. A physics controlled mesh of normal element size in the four domains of study. Mesh generated consisted of 6,556 domain elements and 576 boundary elements. The finite element method was employed to solve the governing equations. The simulation of the thermal process is then carried out for the 7 different zones according to their time-temperature combination as shown in the plate 3. Each simulation time range for the different zone range from zone varied from 3 to 6 minutes with a time step size of 1second. The number of degrees solved for is 28974 (plus 872internal DOFs).

Governing equations

The software COMSOL Multiphysics was used to solve the continuity, momentum and energy equations for the defined geometry and associated boundary conditions. The generalized boundary transport equations are as stated below:

Continuity Equation; Equation 1 is the unsteady, three-dimensional, mass conservation or continuity equation for the simplified case of a fluid flow.

$$\frac{\partial \rho}{\partial t} + \rho\nabla.(u) = 0 \quad (1)$$

where, u is velocity vector(m/s), ρ is density (kg/m3)

Momentum equation; Equation 2 is the incompressible, three dimensional, momentum equation for the simplified case of fluid flow within the system.

$$\rho\frac{\partial u}{\partial t} + \rho(u.\nabla)u = \nabla.[-\rho l + \mu(\nabla u + (\nabla u)^T)] + F \quad (2)$$

where, p is pressure (Pa), μ is dynamic viscosity (kg/m.s) and F is the body force (N).

$$F = -(\rho - \rho_{ref})\, g \quad (3)$$

Energy equation; Equation 3 is the conservation of energy, three dimensional, heat transfer equation for the simplified case of heat transfer within the system.

$$\rho C_p\frac{\partial T}{\partial t} + \rho C_p u.\nabla T = \nabla.(K\nabla T) \quad (4)$$

Where, k is thermal conductivity (W/m.K), Cp is the specific heat capacity (J/kg.K) and T is the temperature (k)

Boundary conditions

Thermo-physical properties of beer, headspace, glass bottle and metal cap are listed in table 1. In order to simplify the problem to be solve with these equations the following initial and boundary conditions where defined in the case study. No slip condition (u = 0) was applied was applied in the inner wall of the glass bottle. The heating of the package wall was assumed to be uniform throughout the process, equal to the spray water temperature at the respective zones. The exit temperature of the bottle beer from the previous zone was set as its inlet temperature in the next zone. The spray water temperature was assumed to remain constant in the different zones throughout the process. The packaged bottled beer was assumed to be at uniform initial temperature of 2oC just before entering the tunnel pasteurizer and the velocity of the fluid currents are null initially.

Properties	Value	Properties	Value
For metal cap		For Glass bottle	
Density(kg/m^3)	2500	Density(kg/m^3)	2500
Specific heat capacity(J/kg.K)	750	Specific heat capacity(J/kg.K)	750
Thermal conductivity(W/m.k)	237	Thermal conductivity(W/m.k)	1.4

Pasteurization Unit

The application of heat during pasteurization causes microbial destruction. The final quality of the product depends upon the amount of heat it has received. The degree of heat treatment or pasteurization effect is expressed is in terms of Pasteurization Units (PU). PU is defined as the effect achieved through one minute of heating at 600C. According to (Horn et al, 1997) studies of Del Vecchio beer spoilage organisms form the basis of this definition which can be written as;

$$PU = t10^{\frac{T-T_{ref}}{z}} \quad (5)$$

or expressed as a rate;

$$\frac{d(PU)}{dt} = 10^{\frac{T-T_{ref}}{z}} \quad (6)$$

with Tref = 60oC and z = 6.94K.

RESULTS AND DISCUSSION

Axisymmetric plot for the beer bottle during pasteurization

Fig 3.1 to Fig 3.8 shows the 3D axisymmetric temperature plot for the beer bottle during pasteurization. It was found in fig 3.1 that at the 1st preheat zone after 350 seconds the temperature distribution within the bottle changed over time as the beer was being heated, and that the slowest heating zone was formed at the bottom of the bottle, due to changes in viscosity and density that caused lower density fluid to rise above fluid of higher density. It was also found in fig 3.2(a-b) from the difference between the temperature distribution within the beer bottle at 60 seconds, and 200 seconds that the head space air in the bottle beer a faster increase in temperature than the beer due to the lower viscosity, and heat capacity of air. In fig 3.3(a-b) showing the 3D axisymmetric temperature plot after 30 seconds, 180 seconds, and 360 seconds in the superheat zone. The temperature difference within the beer was found to decrease gradually as the bottled beer tended towards thermal equilibrium, also slowest heating zone continued to move downward according to the density difference caused by the temperature gradient created over time resulting in recirculation phenomenon within the bottled beer. From fig 3.4 showing 3D axisymmetric temperature plot at 360 seconds in the holding zone it was really clear, that the bottle beer over time reaches thermal equilibrium before it left this zone, as a result of the natural convection current (recirculation phenomenon) created within the bottled beer during the pasteurization process over time as explained earlier. From fig 3.5 showing 3D axisymmetric temperature plot at 30 seconds, and 220 seconds in the Pre-cool zone, the beer temperature was noticed to decrease much slower than the headspace air temperature over time, due to the lower heat capacity and viscosity of the headspace air compared to that of the beer, also from fig 3.6 showing the 3D axisymmetric temperature at 120 seconds, that the temperature of the beer in the bottle is almost reaches thermal equilibrium. In fig 3.7 it can be observed from the 3D axisymmetric temperature plot at 300seconds, and 360seconds, that the beer bottle approaches thermal equilibrium towards the ending of the cooling process in the last unit. In fig 3.8 showing temperature plot of bottled beer in different zones of the tunnel pasteurizer at different time intervals, it is evident that the slowest heating zone is continuously occurring at the bottom region of the beer, which is due to the recirculation discussed earlier. This recirculation effect was observed form heating in fluids in other similar studies in (Lespinard, and Masheroni, 2014), (Radhika et al, 2011), and (Kaluri, and Basak, 2013), revealing continues the importance of natural convention in this thermal process.

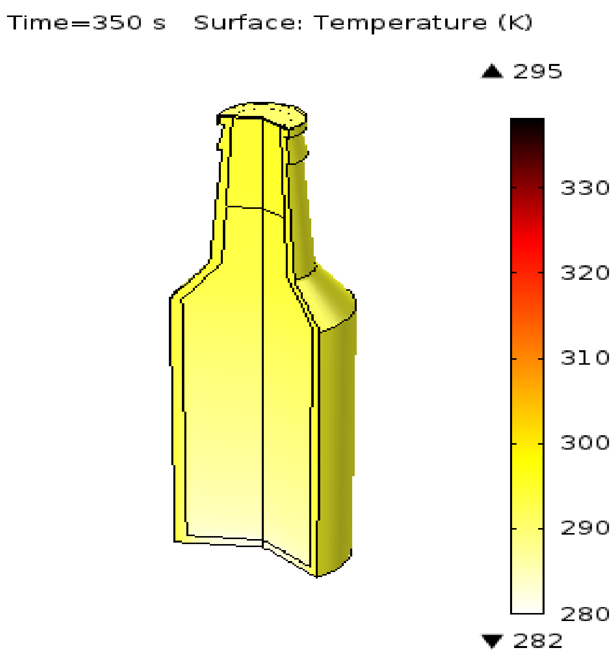
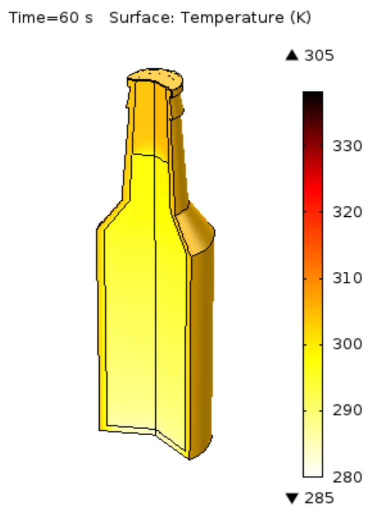
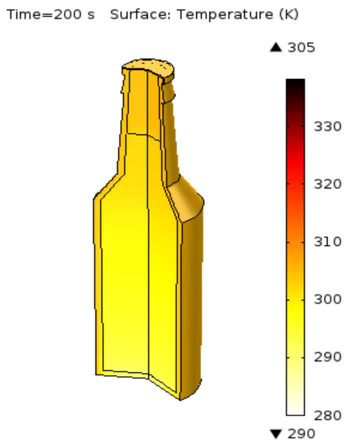


Figure 3.1: 3D axisymmetric plot of the temperature distribution of bottled beer in 1st preheat zone, att 350s in the zone.

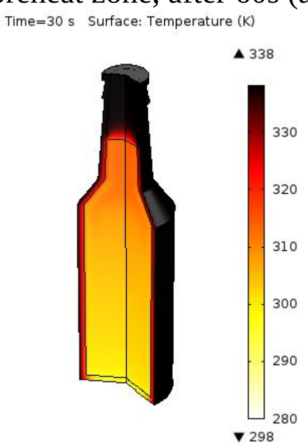


(a) After 60s

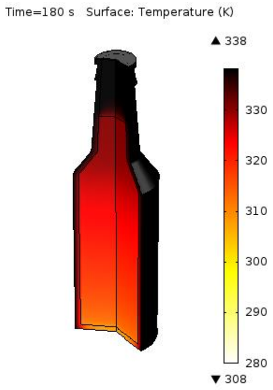


(b) After 200s

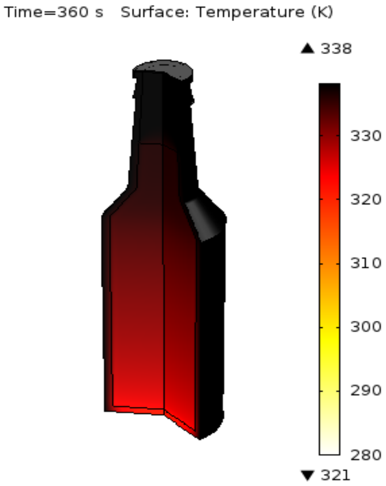
Figure 3.2: 3D axisymmetric plot of the temperature distribution of bottled beer in 2nd preheat zone, after 60s (a) and 200s (b) in the zone.



(a) After 30s



(b) After 180s



(c) After 360s

Figure 3.3: 3D axisymmetric plot of the temperature distribution of bottled beer in superheat zone, after 30(a), 180s (b), and 360s (c) in the zone

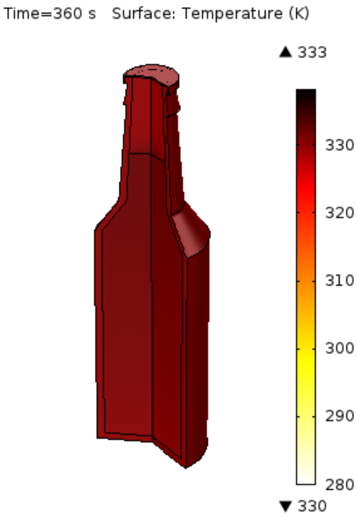
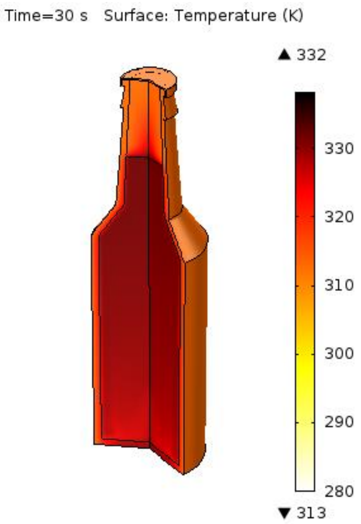
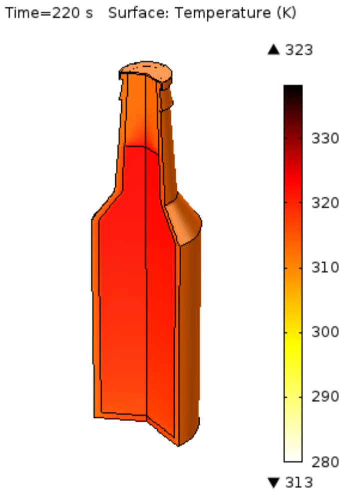


Figure 3.4: 3D axisymmetric plot of the temperature distribution of the bottled beer in Holding zone, after 360s in the zone.



(a) After 30s



(b) After 220s

Figure 3.5: 3D axisymmetric plot of the temperature distribution of the bottled beer in the pre cool zone, after 30s (a) and 220s (b) in the zone.

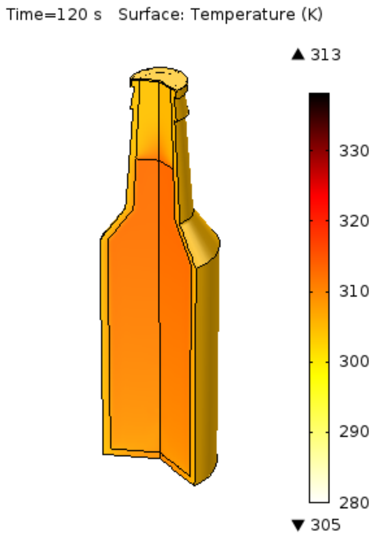
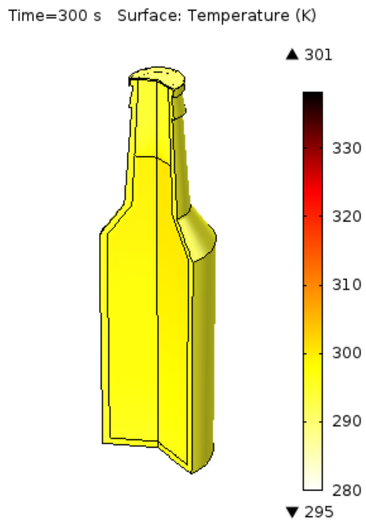
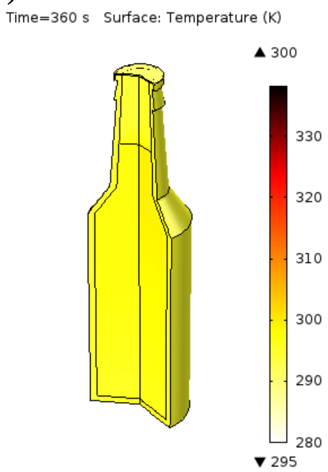


Figure 3.6: 3D axisymmetric plot of the temperature distribution of the bottled beer in the cooling zone 1, after 120s.



(a) After 300s



(b)After 360s

Figure 3.7: 3D axisymmetric plot of the temperature distribution of the bottled beer in the cooling zone 2, after 300s (a) and 360s (b) in the zone.

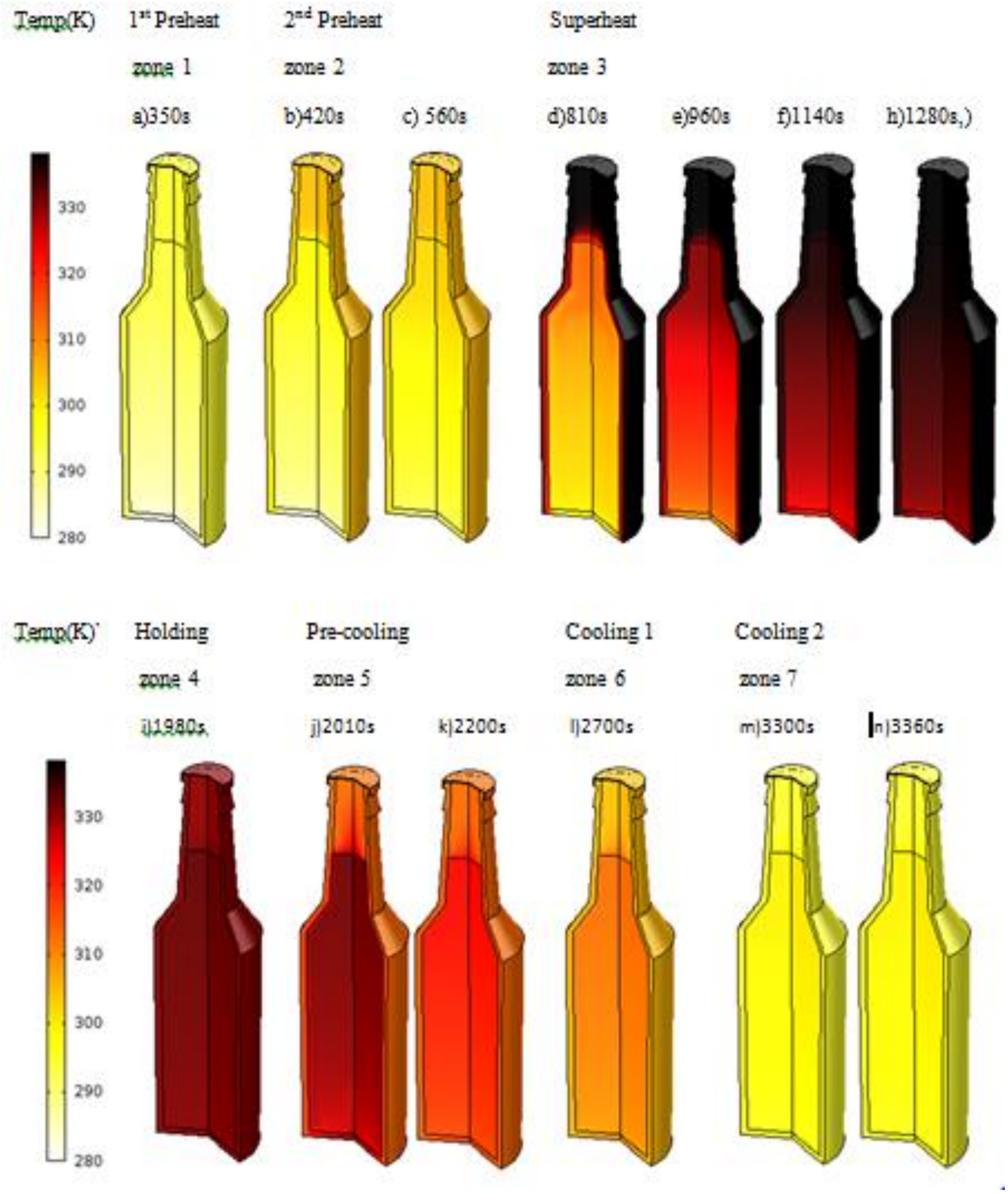


Figure 3.8; Temperature profiles of bottled beer in different zones of tunnel pasteurizer at different time intervals.

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Temperature profiles of beer bottle during pasteurization.

Fig 3.9 to fig 3.10 shows temperature profile at three points 1, 2, and 3 taken from the axisymmetric line inside the beer point 1 - 1.84cm, point 2 – 8.83cm, and point 3 – 18.5cm from the bottom of the bottle respectively. In fig 3.9 shows the temperature profile of the three points at the geometric centre within the beer bottle for the 7 zone tunnel pasteurization process. It is observed that point 3 (the higher point) was heated much faster than the lower point 1 and point 2, which justifies the location of the slowest heating zone toward the bottom of the bottle as discussed above, majorly as a result of the action of natural convection inside the bottle which forces the slowest heating zone to migrate towards the bottom of the container similar observation were made in (Augusto et al, 2010) and (Bhuvaneswari and Anandharamkrihnan, 2014). Fig 3.10(a-g) shows the temperature profile at the three points in the 1st preheat zone, 2nd preheat zone, superheat zone, holding zone, pre-cool zone, cooling 1 zone and cooling 2 zone. In fig 3.10a showing the temperature profile at the points in 1st preheat zone, it is observed that the temperature increases at the three points rapidly, during the initial period of heating, with the top point reaching the highest temperature due to natural convection which forces higher temperature fluid to the top of the bottle and the temperature difference between the bottle walls and the spray water in the 1st preheat zone. In fig 3.10b showing the temperature profile at the three points taken in the 2nd preheat zone, it is observed that the temperature increases quite fast over time, obtaining an almost constant temperature difference at the initial period of heating in the 2nd preheat zone, and getting close to thermal equilibrium at the end due to relative thermal proximity of the bottle walls and the spray water temperature. In fig 3.10c showing the temperature profile at the three points in the superheat zone, temperature are the points are observed to increases rapidly obtaining their highest processing temperature from the temperature profile, due to the high spray water temperature. In fig 3.10d showing the temperature profile at the three points in the holding zone, the temperature at the points are observed to decrease gradually maintain almost constant temperature difference in the heat period and approximating thermal equilibrium at the end of the heating period in the holding zone, due to the fact that the temperature of the bottle and the spray water are of little difference an average of 10oC temperature drop is observed. In fig 3.10e showing the temperature profile at the three points in the precool zone, its observed that the temperatures decrease gradually over the cooling period with an average of 10oC drop at the three points. Also In fig 3.10f showing the temperature profile at the three points in the cooling 1 zone, it is observed that the temperatures decrease gradually over the cooling period with an average of 6oC drop at the three points, In fig 3.10f showing the temperature profile at the three points in the cooling 2 zone, it is observed that the temperatures decrease gradually over the cooling period with an average of 12oC drop at the three points. Thus the temperature profiles show a uniform variation in temperatue throughtout pasteurization in the tunnel pasteurizer this is explained by the natural convection occurring in the beer bottle due to the temperature gradient as already discussed.

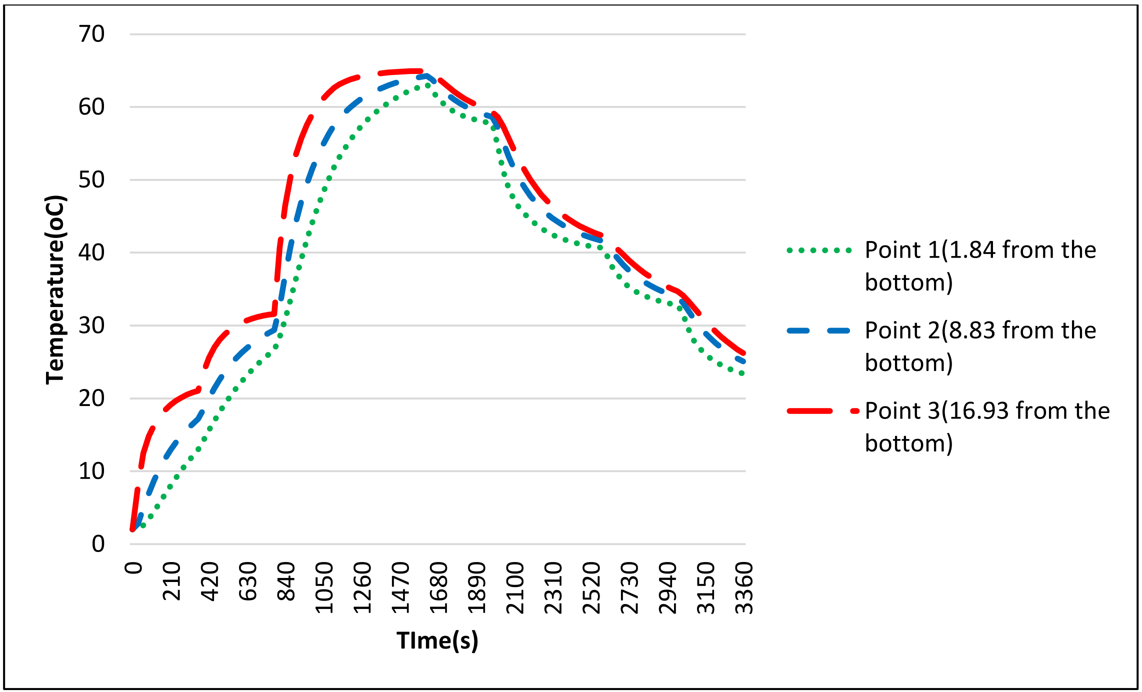
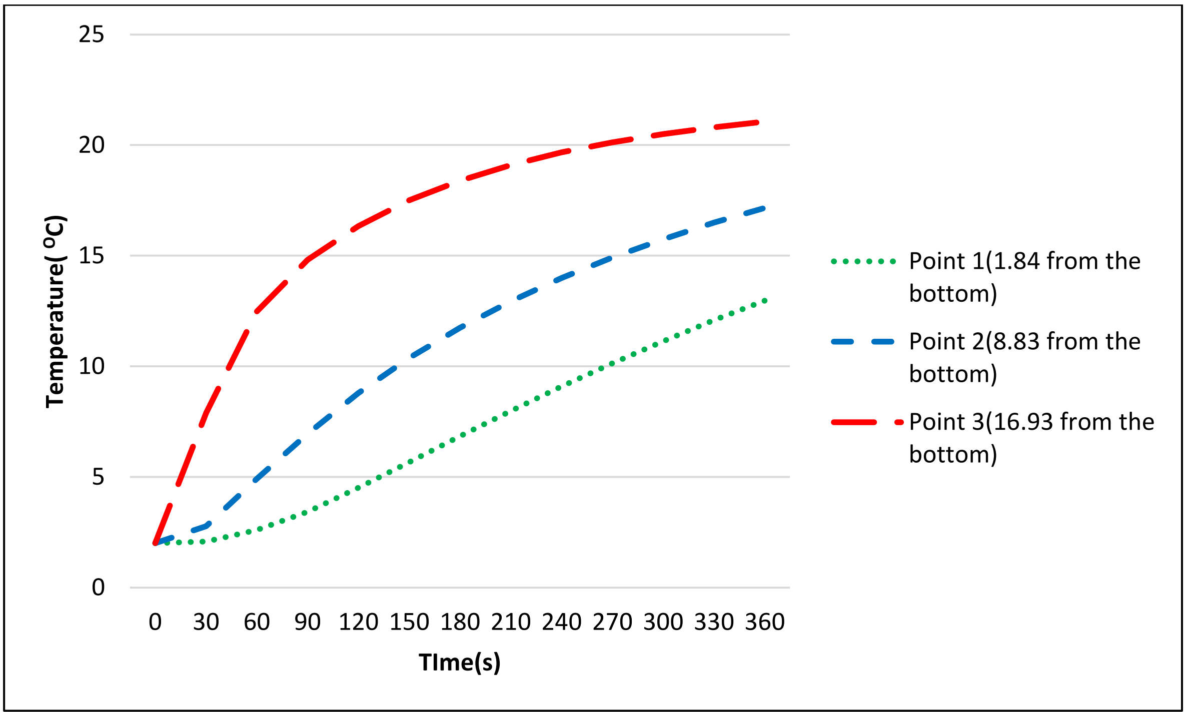
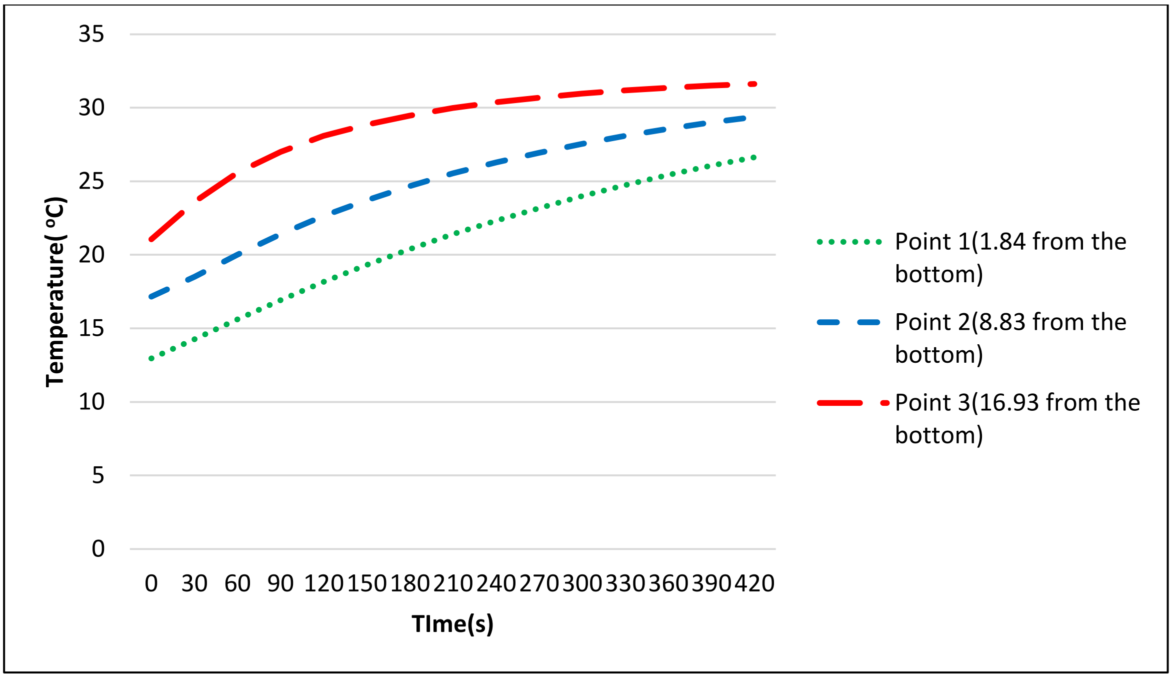


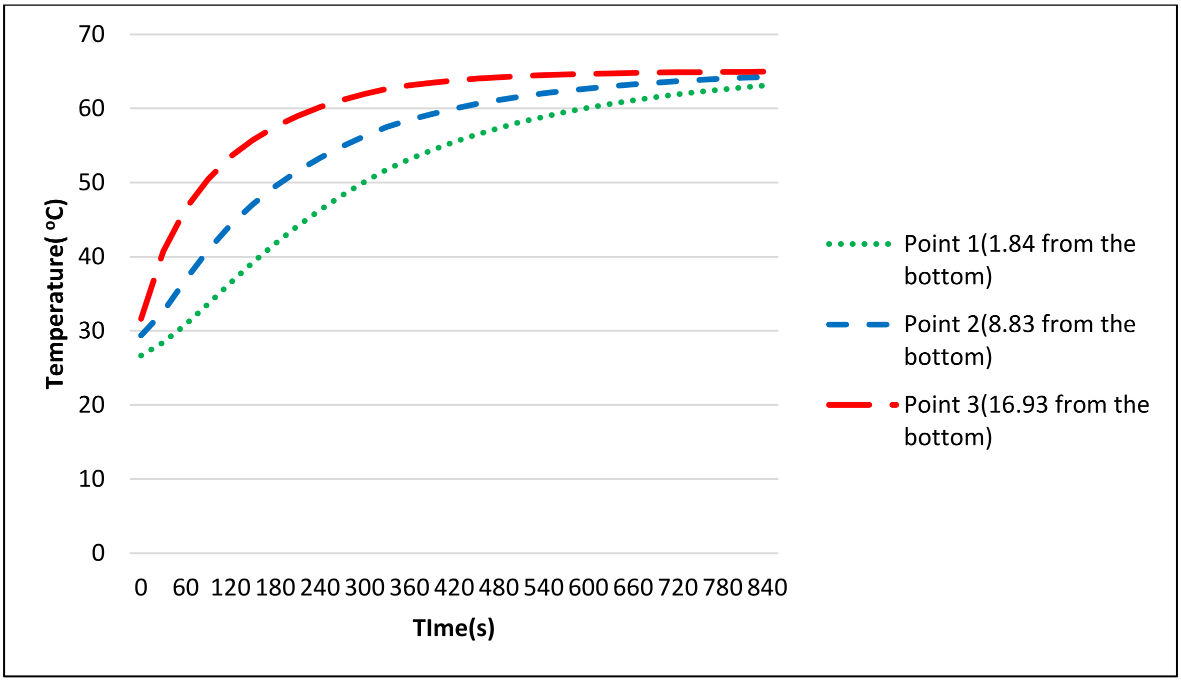
Figure 3.9: CFD simulated temperature profiles(of the three points) at the geometric centree within the beer bottle for the 7 zone tunnel pasteurization.



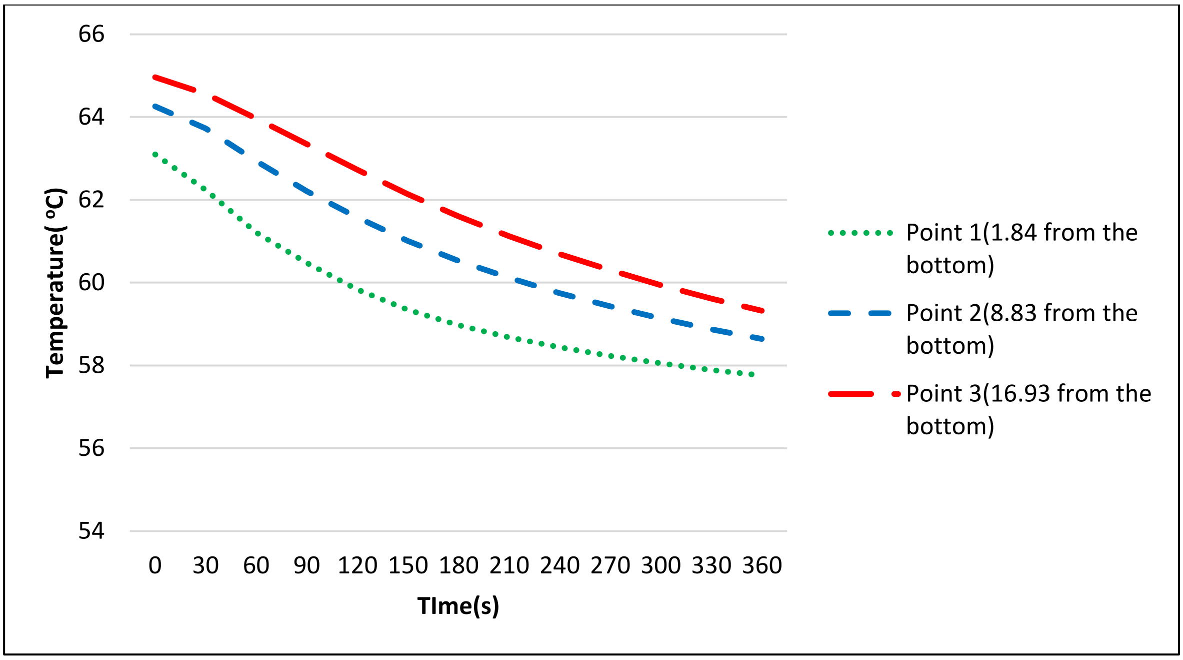
(a) The 1st preheat zone



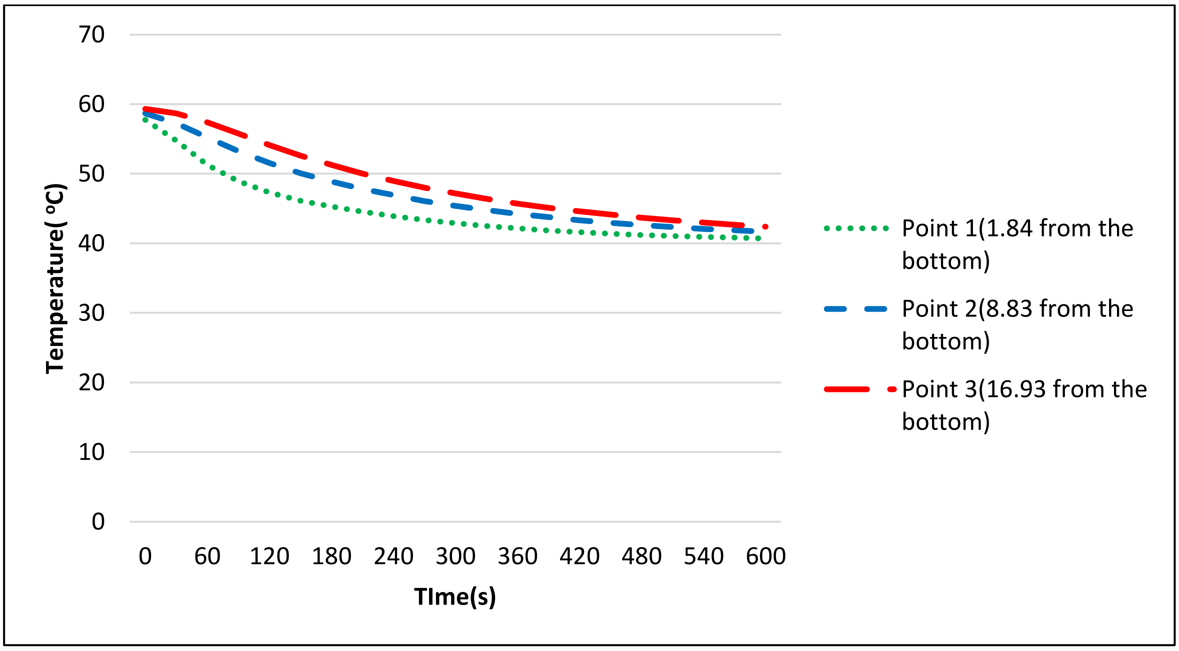
(b) The 2nd preheat zone.



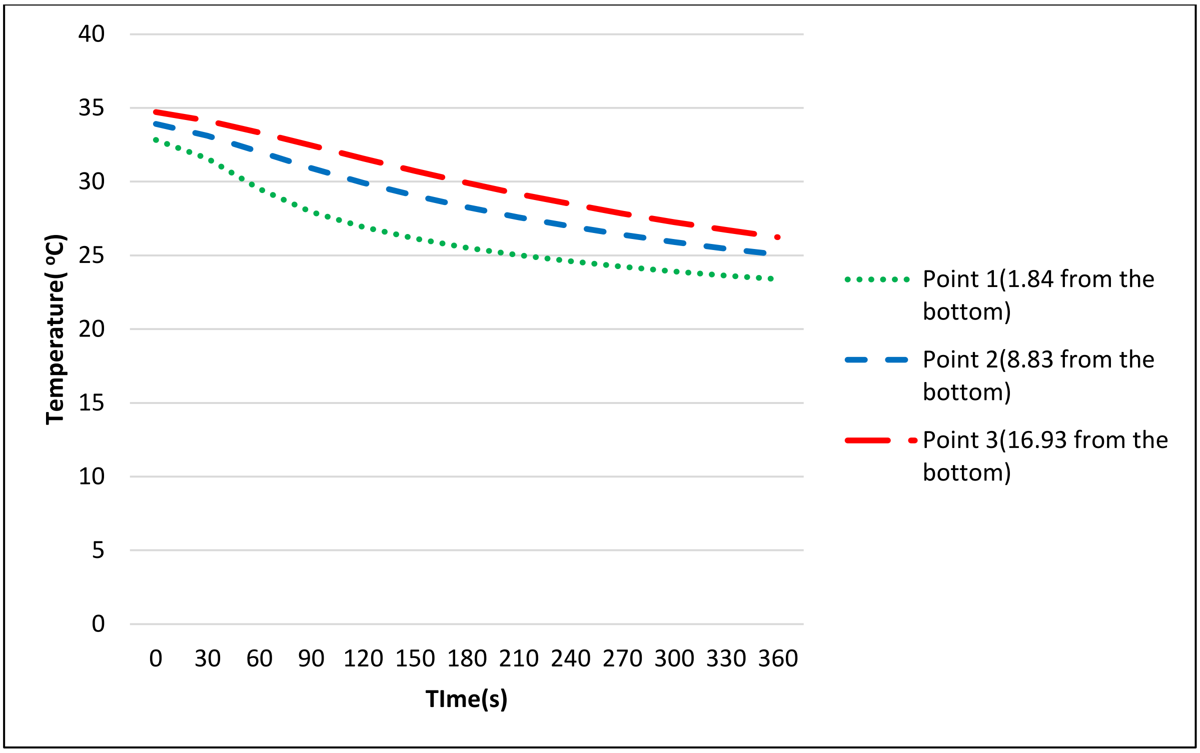
(c) The superheat zone.



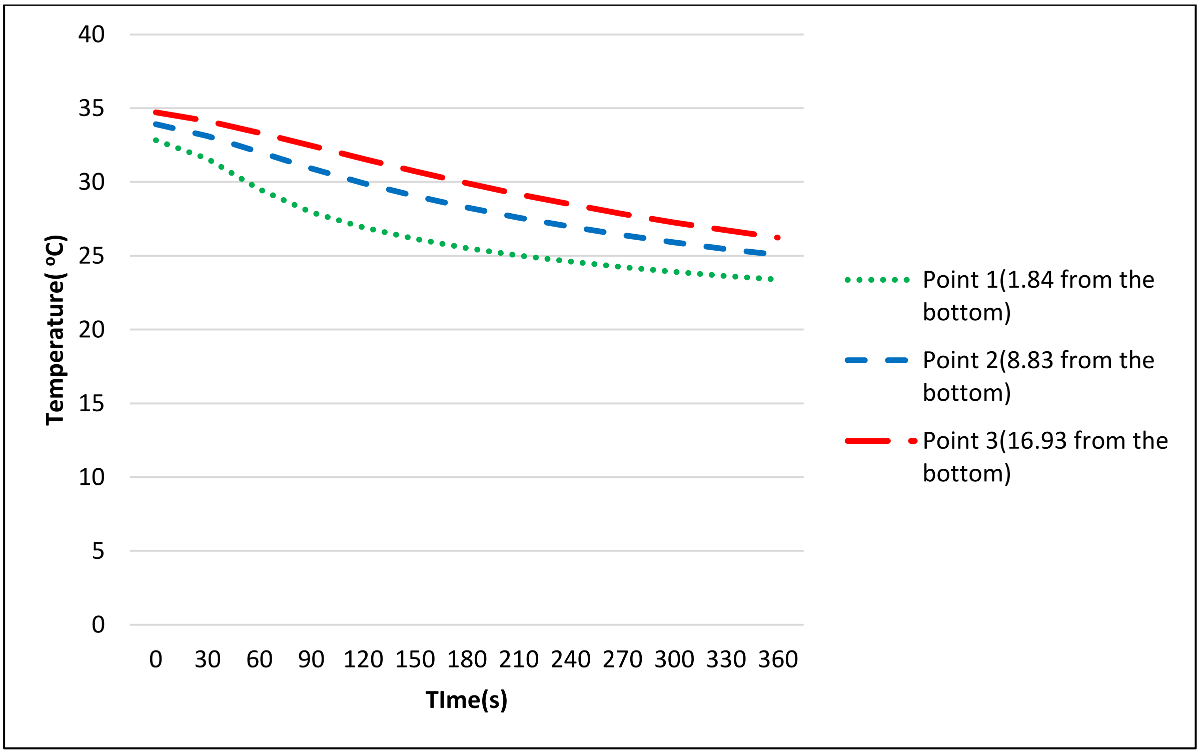
(d) The Holding zone



(e) The Pre-cool zone



(f) The cooling zone 1



(g) The cooling zone 2

Figure 3.10: CFD simulated temperature profiles at three points within the beer bottle during the 7 zone tunnel pasteurization.

PU value against time

The degree of inactivation of the target microorganism Saccharomyces cerevisae (yeast) was evaluated using equation 2.1, for the values of temperature gotten at three points defined in figure 3.11 inside the beer bottle. The PU/min value were calculated for every 30s (0.5min) of the thermal process, refer to appendix for table. Figure 3.11 shows that the highest values of PU/min occurs at the superheat zone where the spray water temperature was maintained at 650C. A similar occurrence was shown by (Bhubaneswari, Anandharamakrihnan, 2014) in their experiment of stationary bottle beer pasteurization. Figure 3.11 also showed that all the three points followed similar trends of inactivation with slight variations due to a uniform variation in temperature from the top to the bottom, and due to natural convection. The PU for all the points were calculated which resulted in 20.91, 60.35, and 109.71for points 1, 2, and 3 respectively. Beer pasteurization with 15 – 30 PU is considered to be safe practice (Breggs et al, 2004). This implies that the tunnel pasteurizer would require some adjustment in its design for more effective pasteurization mainly in the 3 and 4 zones to achieve the required inactivation of saccharomyces cerevisae without over-pasteurization.

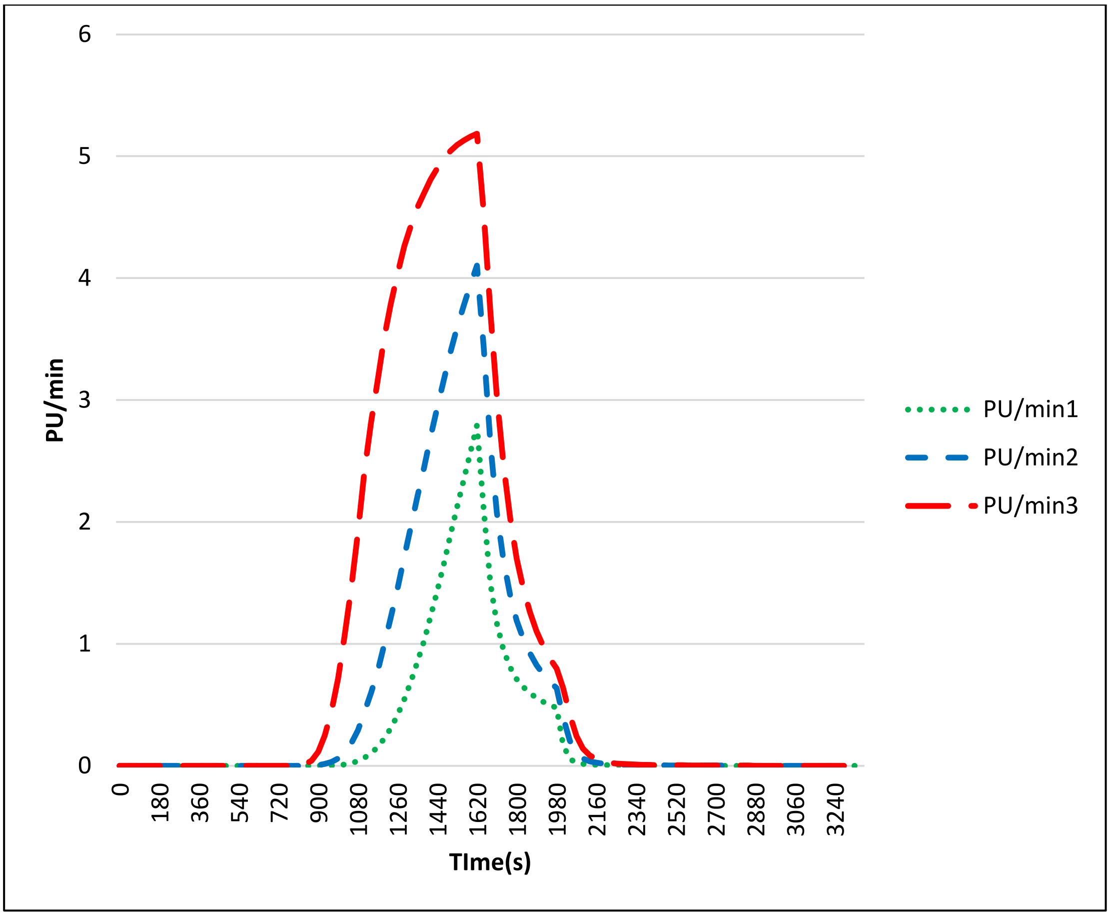


Figure 3.11: PU/min calculated within bottled beer at axisymmetric line for all zones. (point 1 – 1.84cm, point 2 – 8.83cm and point 3 – 16.93cm from the base of the bottle)

CONCLUSIONS

The work concludes that for effective pasteurization to be achieved, there is a need to optimize the spray water temperature and the time spent by the bottled product in each zone of the tunnel pasteurizer, also that the slowest heating zone must occur at the region close to the bottom of the bottle, temperature profile variation must be uniform throughout the process. This study is unique in terms of offering a Computational fluid dynamics model using COMSOL that can be modified to carry out a heat transfer analysis on the tunnel pasteurization of any bottled liquid food.

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