Using Computer Simulation in the Study of Heating and Cooling of Liquid Model Using Computational Fluid Dynamics

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***Abstract*—Heating and cooling process for three dimensional pouch are presented and analyzed in this work. Profiles of transient temperature and the form of Lowest Heating Zone (LHZ) and Lowest Cooling Zone (LCZ) are also analyzed and studied. The process of heating and cooling are simulated for 3200 s and 1000 s respectively. Computational Fluid Dynamics software package PHOENICS was used in this study. Saturated steam at 121^{o}C is used for the heating process and water at 25oC, for the cooling process. The governing equations (Navier Stocks equations) for continuity, energy, and momentum in three directions are solved numerically using a Finite Volume Method (FVM). Viscosity and density of liquid model are assumed temperature dependent. At the end of heating, the LHZ is settled around 30% of pouch's height from its bottom, while in the process of cooling, the LCZ is gradually transferred towards the wide end of pouch at around 70% of pouch's height from its bottom.**

***Index Terms*—temperature distribution, computational fluid dynamics, lowest heating zone, lowest cooling zone.**

I. INTRODUCTION

During the sterilization process of liquids, the heat is transferred into the liquid either by conduction, convection or both conduction and convection [1]. In most processes, conduction and convection occur simultaneously. Normally, the convection current starting when the temperature of fluid is changed, this change will result in changing the density and thus create a natural convection current. This will result in the shifting bulk, such as those for liquid inside can or pouch during this process [2]. In the process of thermal sterilization, the Lowest Heating Zone (LHZ) and thermal center must be known, especially if the study and analysis is for liquid food material.

There is an increasing interest towards the use of theoretical working to predict the distribution of temperature during thermal sterilization process [3-7]. This is due to the expected errors that could happened during the measurement of temperature, as the presence of thermocouples may lead to the disturbance of fluid flow and restrict the liquid's free movement [8].

Different simulation works have been done for liquid models, especially liquid foods under thermal sterilization. These includes the study of natural convection for a low viscosity liquid food in cans [9], and the heat transfer for a non-Newtonian liquid with viscosity depending on temperature [10-13]. Thermal sterilization of liquid foods in three dimensional pouches is also studied and analyzed [14]. The retort pouches are a packaging type that made from alterable laminate plastic and metal foils. It has a wide range of uses from food, field rations to space food [15].

II. MODEL EQUATIONS

The simulations were carried out for a 3D pouch having a width (W), height (H), and length (L) of 0.12 m, 0.04 m and 0.22 m respectively. The top, bottom and sides of the pouch were assumed to be heated at steam temperature of 121^{o}C.

III. COMPUTATIONAL DOMAIN GRID

The pouch volume was divided to six thousand cells in total, which are 20, 10, and 30 cells for the directions of x, y, and z respectively (Fig. 1).

The simulation for both heating and cooling cycles was 4200 seconds (3200 seconds for cooling and 1000 seconds for heating).

The cooling cycle was divided to 20 time steps to target the total heating time of 3200 seconds, and another 10 time steps for the rest of the process (cooling cycle). Different grid mesh and time steps were used and the results shows small dependent on grid mesh change with independent time steps.

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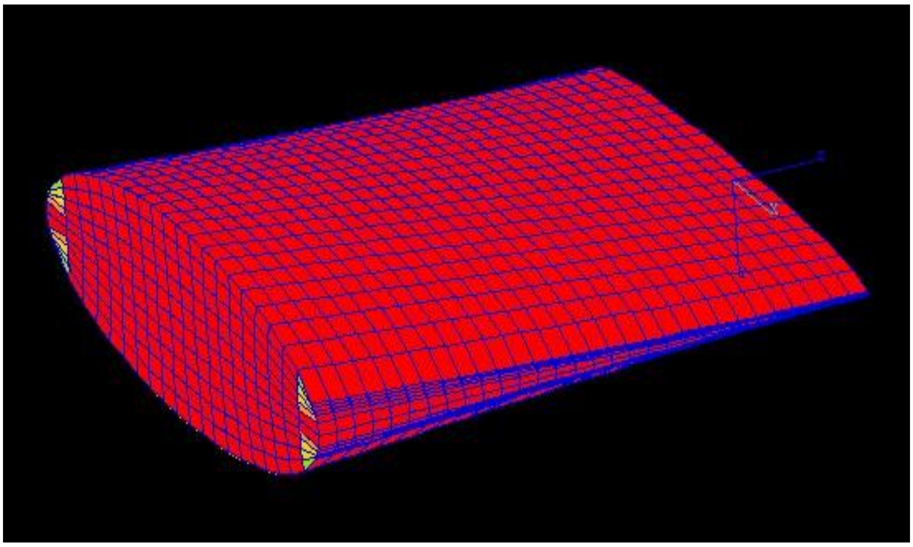
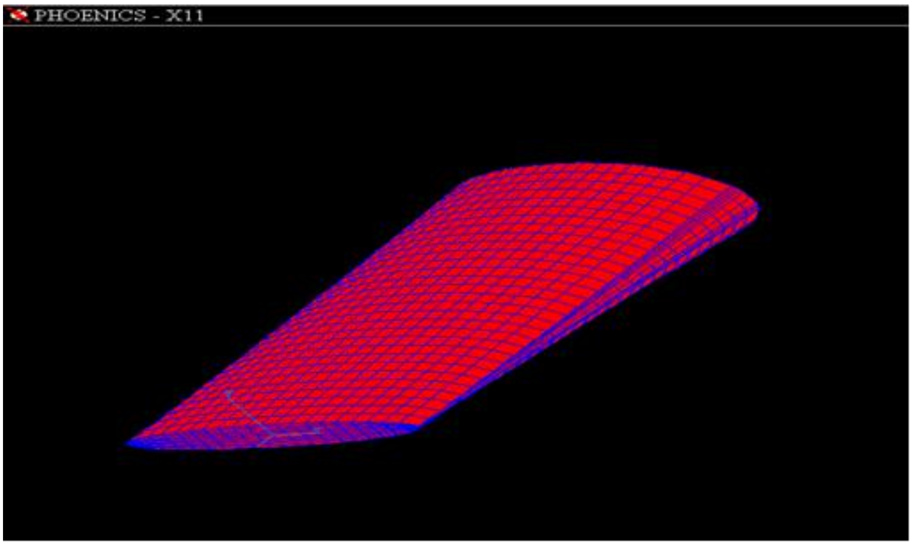


(a) Pouch wide end



(b) Pouch narrow end

Figure 1. Pouch geometry and grid mesh

IV. MODEL EQUATIONS

The Navier Stocks equations are used in the simulation for the three dimensions' case used in this work.

The continuity equation

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0 \qquad (1)$$

The energy equation

$$\frac{\partial T}{\partial t}+v_x\frac{\partial T}{\partial x}+v_y\frac{\partial T}{\partial y}+v_z\frac{\partial T}{\partial z}=$$
$$\frac{k}{\rho C_p}[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}] \qquad (2)$$

The momentum equation in y-direction

$$\rho(\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}+v_z\frac{\partial v}{\partial z})=$$
$$-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}(\mu\frac{\partial v_y}{\partial x})+\frac{\partial}{\partial y}(\mu\frac{\partial v_y}{\partial y})+$$
$$\frac{\partial}{\partial z}(\mu\frac{\partial v_y}{\partial z})+\rho_{ref}\,g(1-\beta(T-T_{ref})) \quad (3)$$

The temperature T is equal to the temperature of the wall T_{wall}, while the velocities at the three directions v_x, v_y, v_z are assumed zero, at the pouch side walls, top, and bottom. In the initial conditions, velocities in all directions are also assumed zero as those in boundary conditions but the temperature T is assumed equal to the reference temperature T_{ref}. For the case of cooling cycle after the process of heating, the wall temperature is assumed equal to 25°C, and the coefficient of heat transfer is used in the simulation.

The liquid model used is the Carboxyl Methyl Cellulose CMC. The physical properties for density, specific heat, thermal conductivity and volume expansion coefficient used in the simulation are assumed constants and its values are 950 kg m-3, 4100 Jkg-1 K-1, 0.7 Wm-1K-1, and 0.0002 K-1respectively. The density is assumed varies in momentum equation in y-direction with the gravitational force (Boussinesq Approximation).

V. Discussion

At the starting of the heating, the temperature contour looks almost same as in the case of conduction heating only. As heating proceed, the heat transfer changed from the case of conduction to that for convection.

At the subsequent stages, the profile of temperature is completely influenced by convection. The circulation of flow is appeared clearly at the end of heating process, which is due the difference in temperature between the pouch's wall and the liquid. These findings were fully investigated by Ghani et al. [16],

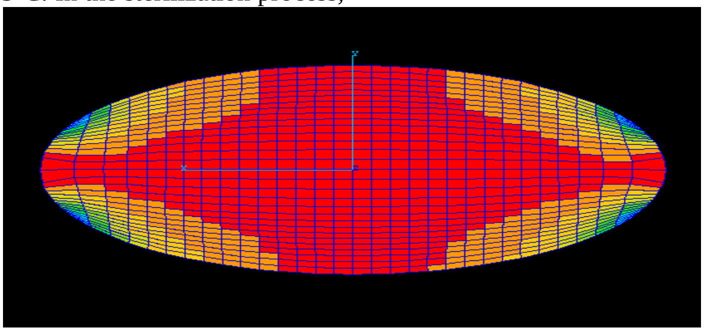
During the 10 minutes of holding time from the minutes 60 to 70, the pouch temperature was remained uniform at temperature121^{o}C. The maximum difference in the temperature of LHZ was 0.5^{o}C. In the sterilization process, the holding time is quite important because it remains the pouch at its maximum temperature

In this work, the distribution of temperature and the transmigration of Lowest Heating Zone LHZ and Lowest Cooling Zone LCZ during heating and cooling process respectively, is analyzed and studied.

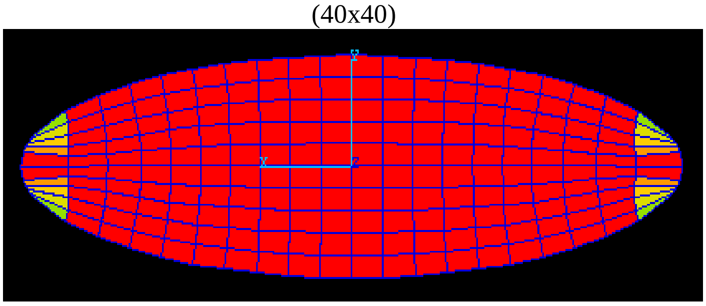
Body Fitted Coordinate was used in this simulation for the purpose of generating the pouch's geometry. In the simulations of this work, several grid sizes and time steps were used, and by the use of mesh refinement study, the optimum mesh found was 20x10, which is because of the orthogonal cells of dominant that lead to amelioration in the solution's stability (Fig. 2).

The obtained results showed that the solution used in this study is mostly time step independent and slightly dependent on the size of the grid used.

The simulations results are presented in Figs. 3-6. Fig. 6 shows clearly the location of LCZ in the pouch lower part, while this zone (LCZ) is moved towards the pouch wide end as a result of convection currents.



(40x40)



(20x10)

Figure 2. Different grid meshes used to test the pouch cells

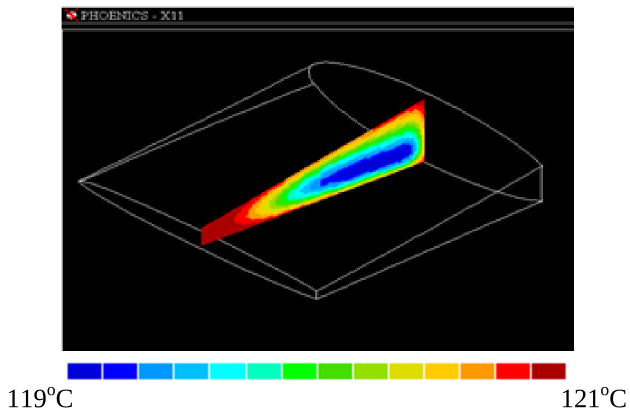


Figure 3. Temperature profiles at 50% pouch distance from side wall at the end of heating

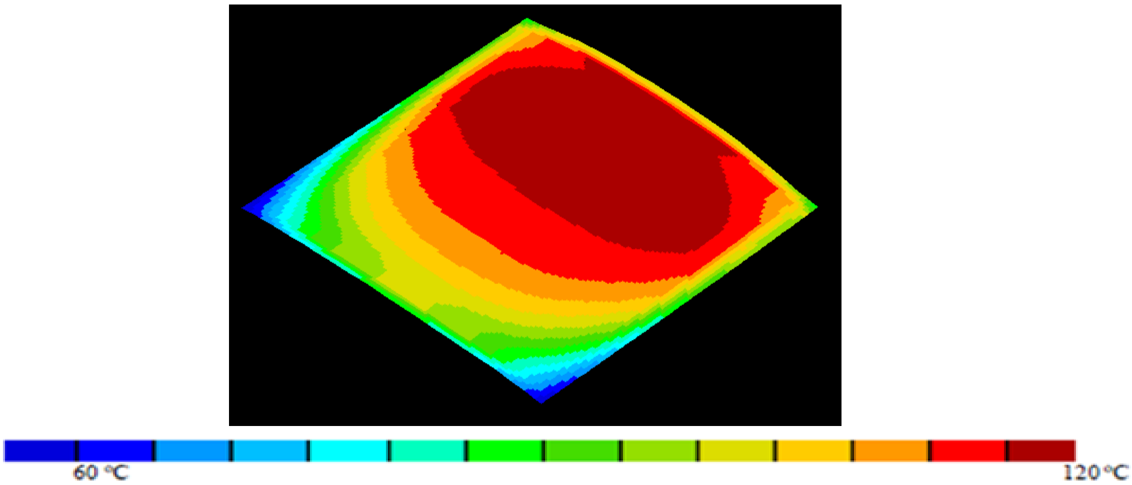


Figure 4. Temperature contours in y-planes after 600 from the beginning of cooling process (70% pouch height)

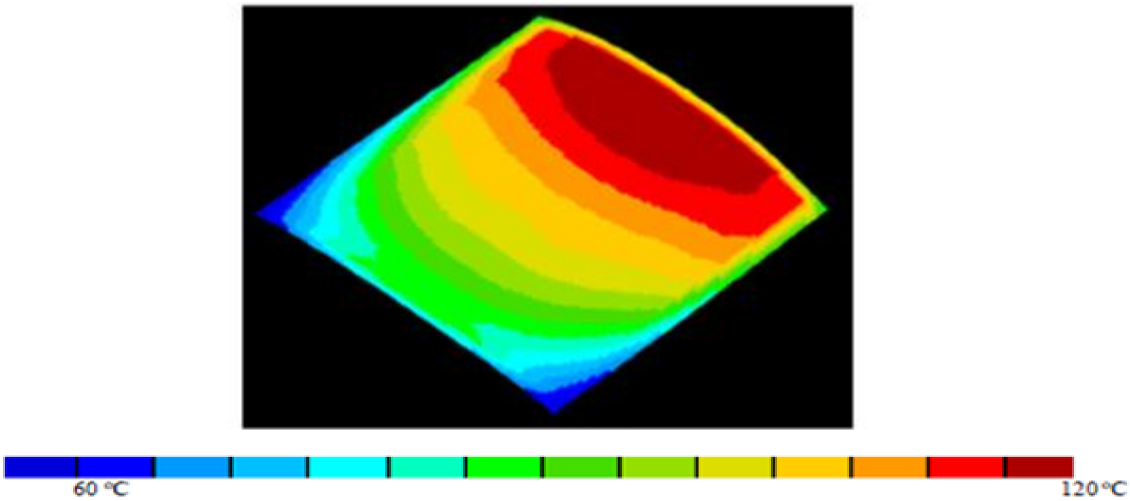


Figure 5. Temperature contours in y-planes after 600 seconds from the beginning of cooling process (80% pouch height)

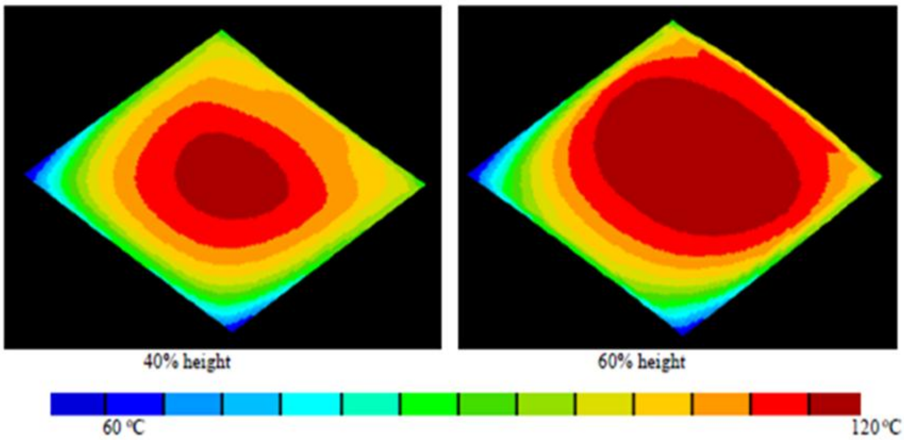


Figure 6. Temperature contours after 900 s from the beginning of cooling process (40% and 60% pouch height)

VI. Conclusions

Temperature distributions and the formations of lowest heating and lowest cooling zones during the process of natural convection heating and cooling in a 3D pouch filled with viscous liquid model (Carboxyl Methyl Cellulose CMC) is analyzed and studied. The governing equations (Navier Stocks) for mass, energy, and momentum in three dimensions are solved using a finite volume method software package PHOENICS. At the end of heating, the lowest heating zone is found stabilized at 30 or 40% of pouch's bottom, and around 20-30 % from its wide end. During the process of cooling, the LCZ is also found transferred towards the wide end of the pouch at around 80 % of its height.

NOTATION

CP	specific heat of liquid food (J kg $^{-1}$ K^{-1})
F	heating or cooling factors
H	height of the pouch (m)
k	thermal conductivity of heated liquid (W m^{-1} K^{-1})
L	length of the pouch (m)
t	heating time (s)
T	temperature (°C)
Tref	reference temperature (C)
Tw	wall temperature (C)
vx	velocity component in the x direction (ms–1)
vy	velocity component in the y direction (ms–1)
vz	velocity component in the z direction (ms –1)
W	width of the pouch (m)
β	thermal expansion coefficient (K-1)
μ	viscosity (Pa.s)
ρ	density (kg m-3)
ρ_{ref}	reference density (kg m-3)

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

Ghani Albaali designed, coordinate the research with the drafted of the manuscript. Ahmad Shawaqfeh carried out the simulations and some of the analysis. The authors read and approved the final version of manuscript.

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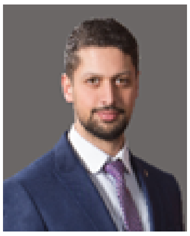

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