Environment control for beef freezing simulation and determination of thermal characteristics

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Abstract. Beef is a meat products obtained from cows which is commonly used for food consumption. To determine the optimum freezing, we have to recognize the freezing rate and heat properties of the product during the freezing process. The aim of this study is to simulate the heat properties and determine optimum rate and time of beef freezing. In compiling simulation program, the programming algorithm is based on mathematical models used to control the surrounding environment for beef freezing purpose. The simulation results showed that during freezing, the temperature continues to decrease from the freezing point of water to the desired final freezing temperature. In this process, water undergoes a phase change from a liquid phase to a solid phase which is marked by the formation of ice crystals. It may conclude that the simulation algorithm can predict changes in the thermal properties of beef during freezing where based on changes in its characteristics the freezing of beef begins to change its thermal properties at the initial freezing temperature of -1.5°C.

1. Introduction
Beef is a meat products obtained from cows which is commonly used for food consumption. In each region, the use of this meat varies depending on the way it is processed. For example, hash meat, rib meat and T-bone are very commonly used in some countries as ingredients for steak so that this part of the cow is very much traded [1]. However, as in Indonesia and in other Asian countries, this meat is widely used for spicy and coconut milk foods such as konro and rendang soup. In addition, there are several other parts of beef such as the tongue, liver, nose, viscera and oxtail which are only used in certain areas as a food base [2].

Moreover, beef contains zinc, phosphorus, selenium, iron and vitamin B. Red beef is the main source of carnitine and creatine. Beef is widely sold in the local market and at the super market in its fresh and processed form. Beef floss and beef sausage are examples of processed beef that are widely consumed and traded in the community. Fresh beef can be preserved by freezing. This method is one of the most widely used preservation methods because it is proven to help extend the shelf life of beef. approach.

To determine the optimum freezing, then we must know the rate of freezing and change the heat properties of the material / product during the freezing process. By knowing the changes in the heat properties of the material and the freezing rate, then we will be able to determine how long it takes for the freezing process, so that the results of freezing are optimum [3], [4].

The heat properties or thermal characteristics of the material that affect the quality of the freezing are the heat conductivity of the material, the density or density of the material and the heat of the material. The three heat properties of this material are generally used to determine the profile or characteristics of materials to be or are being frozen. By knowing the changing pattern of the three heat properties of this material, we will be able to determine the most optimum freezing time and freezing rate so that the frozen food has good quality and may be suitable for export to other countries.
Changes in the heat properties of the material in this case beef during the freezing process is carried out by continuous measurement at specified intervals. Material is removed every time interval and the parameters of the heat properties are measured with appropriate instruments. This method requires that we wait until the freezing process reaches the desired temperature [5]. Therefore, the main objective of this study is to analyze the suitable and optimum environment control for beef freezing and also to determine thermal characteristics changes of beef during process by using computer simulation.

2. Material and Methods
This research was carried out in three consecutive stages, where the first stage was the creation of a computer program used to simulate changes in the thermal properties of beef during freezing, the second stage was the measurement of initial values of thermal conductivity, specific heat and density of the product [6]. While the last stage is freezing beef. Stages and procedures of this study in more detail can be seen in the flowchart as presented in Figure 1.

![Figure 1. Simulation procedures for environment control for beef freezing](image)

Meat material or frozen animal products will experience changes in the characteristics and heat properties of these materials, because as mentioned earlier that the freezing process occurs in the heat transfer between the environment around the freezer and the frozen material. Changes in heat properties of materials include physical properties namely: heat type, thermal conductivity and density of materials.
In compiling simulation program, the programming algorithm is based on mathematical models used to control the surrounding environment for beef freezing purpose. The three main equations used for the prediction and analysis of changes in beef heat during freezing are as follows [1], [7]:

heat capacity \( C_pS = \frac{[ICp - (IWC \cdot \rho W)]}{EMS} \), \( C_p product = \frac{\Delta H}{\Delta T} \) \hspace{1cm} (i)

beef density \( \frac{1}{\rho} = \frac{WC}{\rho W} + \frac{EMI}{\rho l} + \frac{EMS}{\rho S} \), \( \rho S = \left( \frac{1}{\rho 0} - \frac{1}{\rho W} \right) \) \hspace{1cm} (ii)

thermal conductivity \( k = kc\left(\frac{1 - Q}{1 - Q(1 - M^{1/3})}\right) \), \( Q = M^{2/3}\left(1 - \frac{kd}{kc}\right) \) \hspace{1cm} (iii)

In addition to these equations, several constants are also needed as initial values to be used in this analysis. These initial constants and values are the physical properties of water and ice which form an important phase in freezing. These physical properties were used as input to the simulation program.

3. Result and discussion
Freezing means the transfer of heat from the material, which is accompanied by phase changes from liquid to solid, and is one of the common processes carried out for handling foodstuffs. With the freezing of microbial activity and the enzyme system will be hampered so that damage to food will not occur. It is a process of decreasing the temperature of food, from the initial temperature to reaching temperatures below the freezing point of the food itself. The simulation interface for environment control in beef freezing is shown in Figure 2.

During freezing, the temperature continues to decrease from the freezing point of water to the desired final freezing temperature. In this process, water undergoes a phase change from a liquid phase to a solid phase which is marked by the formation of ice crystals. If the freezing continues, ice crystals will form
on the frozen product in this case beef. This continuous formation of ice crystals will injure the cell walls in meat and cause meat nutrition to be lost [8], [9]. The study results show that the pattern of changes in the thermal properties of meat during freezing starts from -1.5 °C.

Beef density decreases during freezing as temperature decreases. This happens because of changes in the composition of water and ice, where ice crystals increase, the volume of water decreases while the total mass as a whole is fixed. This makes the density of beef experience decline during the freezing process as shown in Figure 3.

![Figure 3. Beef density changes during freezing](image)

On the other hand, the heat conductivity of beef during the freezing process is predicted to change exponentially. The heat conductivity of the meat will increase from the initial freezing temperature to -1.5 °C to the temperature the simulated end is -40 °C. This change is caused by the formation of ice crystals that occur during freezing is increasing so that it requires a large amount of heat for the process of heat transfer from sample material to ice as presented in Figure 4.

![Figure 4. Conductivity changes during freezing](image)
The process of heat transfer that occurs during freezing takes place by convection and conduction. Cold air from the freezing media causes heat transfer from higher temperature samples to a lower temperature freezing environment. Convection heat transfer with air fluid continues until it reaches a balance between the system and its environment. Heat transfer by conduction in the freezing process, among others, occurs in the material itself where the amount of heat that moves depends on the temperature difference between the environment and the system, the thickness of the beef material sample and its heat transfer coefficient \cite{10}, \cite{11}.

Beef heat has increased at the beginning of the freezing process due to phase changes from liquid to solid. Furthermore, it will decrease until the end of the freezing process where the enthalpy of the material will decrease in line with the freezing temperature drop as shown in Figure 5.

![Figure 5. Heat energy capacity changes during freezing](image)

The formation of ice crystals in products that are being processed for frozen storage is very interesting, because of the effect it has on the quality of frozen products. This effect is due to the size of the ice crystals and their configuration in the frozen food network. The crystallization process occurs in two stages, namely the formation of the crystal core in the early stages of the crystal, the crystal core then grows larger. Crystallization, this second stage can only take place after the nucleus has formed and reached a critical size \cite{12}, \cite{13}. The rate of crystallization is influenced by the rate of reaction of water molecules on the surface of the crystal, the rate of diffusion of water molecules from the part of the solution that has not yet frozen towards the surface of the crystal and the rate of heat energy transfer.

Freezing time can be defined through two approaches. The first approach is the effective freezing time, which is the freezing time needed to lower the temperature of food from the initial temperature to the desired final temperature at the center of heat \cite{14}, \cite{15}. The second approach is the nominal freezing time which is the time when the food surface reaches 0 °C and the heat center reaches a temperature lower than 10 °C from the initial temperature of ice formation.

4. Conclusion
Based on obtained simulation result, it can be concluded that the computer program can predict changes in the thermal properties of beef during freezing where based on changes in its characteristics the freezing of beef begins to change its thermal properties at the initial freezing temperature of -1.5 °C.

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