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Carne de vaca Enfriamiento al vacío Humedad Migración y componentes nutricionales Simulación numérica

Beef Vacuum Cooling Moisture Migration and Nutritional Components Numerical Simulation

Liu Hao, Lv Chunhui, Wang Peng*
Tianjin Modern Vocational Technical College, Tianjin,300350,China

**Correspondence author: Wang Peng, Email: a445645889@163.com*

Resumen
Con el desarrollo de la sociedad y la mejora del nivel de vida de las personas, las personas están prestando cada vez más atención a la seguridad de los productos cárnicos. En la actualidad, muchas empresas de fabricación de productos de carne de res no pueden garantizar efectivamente la calidad de la carne debido a los métodos inadecuados de enfriamiento de la carne; Incluso debido a la falta de métodos de enfriamiento efectivos, muchos proyectos de desarrollo de productos con alto valor agregado han sido abandonados. Por lo tanto, es muy importante encontrar un nuevo proceso de enfriamiento en lugar del enfriamiento convencional para resolver sus desventajas. Los microbiólogos recomiendan que la temperatura de la carne se reduzca rápidamente, especialmente dentro de un cierto rango de temperatura, las bacterias son particularmente propensas a multiplicarse. El aumento del pH hace que la proteína miofibrilar se desvíe de su punto isoeléctrico, y la carga negativa neta de la proteína es mayor, lo que fortalece la interacción entre proteína y agua y debilita la interacción entre proteína y proteína. El enfriamiento rápido de la carne puede reducir la reproducción bacteriana y reducir la contaminación. En este documento, las características de migración de agua de la carne de res durante el enfriamiento al vacío se estudian a través de experimentos, y se obtienen las leyes de migración de agua durante el enfriamiento al vacío. Se discuten los cambios en los componentes nutricionales del enfriamiento por vacío de carne y se proponen ideas de optimización.

Palabras clave: Enfriamiento al vacío de carne de res; Migración de humedad; Ingredientes nutricionales; Seguridad alimenticia

Abstract
With the development of society and the improvement of people's living standards, people are paying more and more attention to the safety of meat products. At present, many beef product manufacturing enterprises cannot effectively guarantee the quality of meat due to improper meat cooling methods; even because of lack of effective cooling methods, many product development projects with high added value have been abandoned. Therefore, it is very important to find a new cooling process instead of conventional cooling to solve its disadvantages. Microbiologists recommend that the temperature of beef should be reduced quickly, especially within a certain temperature range, bacteria are particularly prone to multiply. Increasing pH makes myofibrillar protein deviate from its isoelectric point, and the net negative charge of the protein is more, which strengthens the interaction between protein and water and weakens the interaction between protein and protein. Rapid cooling of beef can reduce bacterial reproduction and reduce pollution. In this paper, the water migration characteristics of beef during vacuum cooling are studied through experiments, and the laws of water migration during vacuum cooling are obtained. The changes in nutritional components of beef vacuum cooling are discussed, and optimization ideas are proposed.

Key words: Vacuum cooling of beef; Moisture migration; Nutritional ingredients; Food safety

1. Introduction

With the development of society and the improvement of people's living standards, people pay more and more attention to the safety of meat products, especially the safety of cooked beef products, which has been highly valued by people all over the world [1]. In view of the experience and lessons of frequent meat product safety accidents, countries around the world, especially European countries, have formulated a series of meat product production specifications, and also set strict requirements on the cooling process during processing. To reduce the proliferation of bacteria in meat, cooked beef products should be cooled quickly [2].

Vacuum cooling is the use of reduced pressure to reduce the saturation temperature of water so that the water in the product evaporates. Because the heat absorbed during the evaporation process comes from the product itself, it causes the product to cool down. The advantage of vacuum cooling is that the fast cooling speed can correspondingly extend the storage time and shelf life of the product. It can also inhibit the growth and reproduction of microorganisms in the product [3-4]. It can delay the process of changing the chemical composition in the product. Improve the sanitary conditions of the product. Maintain the nutritional value and color of the product. Fragrance and taste improve product quality. Vacuum cooling is easy to operate and is not limited by packaging [5].

Vacuum cooling is a fast pre-cooling technology that is currently very popular in Europe, the United States, and Japan. It has been applied to the pre-cooling of lettuce, mushrooms, cut flowers and other horticultural products very early. In recent years, it has been applied to the pre-cooling of meat and meat products. Vacuum cooling has been considered as a fast and effective cooling method. Vacuum cooling mainly relies on evaporating the water inside the product to absorb heat, which will cause the product to lose part of the water. Water loss will bring certain negative effects to the product [6]. For example, the surface of the fruit can be wrinkled and tarnished. The flower will easily wither after water loss, and the leaves will become soft. This will affect the quality of the product. Although vacuum cooling has many advantages, water loss is the biggest drawback of vacuum cooling. Because the loss of water will change the internal structure of the product, it will have a certain negative impact on the quality of the product, which will limit the large-scale application of vacuum cooling in actual production. Significance [7]. The author mainly theoretically analyzes the internal moisture migration process of cooked beef under vacuum cooling conditions, and establishes a mathematical model of moisture migration during vacuum cooling, and explores the color, taste, and composition of meat products to explore the vacuum cooling of beef. Water migration and changes in nutrients [8].

2. Mathematical Model of Moisture Transfer during Vacuum Cooling of Beef

The speed of vacuum cooling depends on the pressure in the vacuum chamber and the properties of the product. Vacuum cooling mainly absorbs heat by evaporation of water inside the product, which makes the product temperature lower [9]. The vacuum cooling process of cooked beef involves the moisture from the inside of the cooked beef to the surface and the evaporation of moisture on the surface into the vacuum chamber. Moisture migration during vacuum cooling involves the diffusion of free water inside the cooked beef in liquid and vapor forms. However, in general, the diffusion rate of a gas is 10,000 times that of a liquid. Therefore, when establishing a mathematical model of moisture migration during vacuum cooling, compared with gas diffusion, the diffusion of liquid free water can be ignored.

In general, the boiling point of water changes with saturation pressure [10]. When the boiling point of water is 0 ° C, its corresponding saturation pressure is 609 Pa. During the vacuum cooling of cooked beef, when the vacuum pressure in the vacuum chamber is lower than or equal to the saturation pressure corresponding to the temperature of the cooked beef, the moisture inside the cooked beef will evaporate to produce a cooling effect. In the initial stage of vacuum cooling, when the temperature distribution of the product is not uniform, the water will first boil in the higher temperature place, and then the boiling interface will move to the low temperature direction until all the water in the product is boiled. On the other hand, when the initial temperature distribution of the product is uniform, the moisture on the surface of the product will first boil, and then the interface will slowly move to the center [11]. The boiling interface divides the product into two zones: a boiling zone and a non-boiling zone. Water appears in gaseous and liquid form in the boiling zone; water appears only in liquid form in the non-boiling zone. In the following analysis and mathematical model, the research object is a cylindrical cooked beef cut. When establishing a mathematical model, in order to simplify calculations, the following assumptions are made:

1) Consider only one-dimensional heat and mass transfer;

2) In the initial stage of vacuum cooling, the temperature, pressure and moisture content of cooked beef are evenly distributed;

3) The heat convection and radiation on the surface of cooked beef are small and can be ignored. According to the above analysis and assumptions, in the non-boiling region, heat conduction can be expressed by Fourier's law (1):

$$\rho c_p \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial r^2} + \frac{\lambda}{r}\frac{\partial T}{\partial t}$$

Where T - product temperature, ℃; t - product cooling time, s; ρ-product density, kg / m3; cp - product specific heat capacity, J / (kg K); r-Radius of the product, m; λ -Thermal conductivity of the product, W / (m K). Similarly, the pressure distribution (2) in the product can be expressed as:

$$\alpha \frac{\partial P}{\partial t} = k \frac{\partial^2 P}{\partial r^2} + \frac{k}{r}\frac{\partial p}{\partial t}$$

Where P-pressure, Pa; α- pressure diffusion coefficient, Pa^{-1}; k-gas permeability, m2 / (Pa · s). The pressure diffusion coefficient (3) and gas permeability (4) can be expressed as:

$$\alpha = \frac{\omega}{\rho_g R_g T}$$

$$k = \frac{K}{\eta}$$

Where K is the specific permeability of the gas, m2; η is the viscosity of the gas, Pa s; ω is the porosity of cooked meat,%; Rg is the gas constant of water vapor, 461 J / (kg K); gρ-density of water vapor, kg / m3. In the boiling zone, the effect of water boiling on heat transfer should be considered. The governing equation (5) can be expressed by the following formula:

$$\rho c_p \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial r^2} + \frac{\lambda}{r}\frac{\partial T}{\partial t} + q_v$$

In the formula, q_v-the heat absorbed by evaporation of water in a unit volume, W / m3. (6) can be expressed as:

$$q_v = h_v \dot{m}_v$$

Where h_v-the latent heat of evaporation of water vapor, J / kg; m_v——the evaporation rate of water in a unit volume of product, kg / (m3 s). Its expression (7) is:

$$\dot{m}_v = 4\frac{\omega}{d} h_m (\mathrm{P_{sat}} - \mathrm{P})$$

Where d—the diameter of the internal passage of cooked beef, m; h_m—the boiling coefficient, kg / (Pa s m^2); P_{sat}—the saturation pressure corresponding to the temperature of cooked beef, Pa. Its expression (8) is:

$$\mathrm{P_{sat}} = \frac{2}{15} \times 10^3 \exp\left[18.5916 - \frac{3991.11}{T - 39.31}\right]$$

The initial conditions of equations (1), (2), and (5) are as follows:

t = 0, T = T0 (9)

P = P_{sat}, 0 (10)

The boundary conditions of equations (1), (2), and (5) at the center and surface of cooked beef are as follows:

At the cooked beef center (11):

$$\frac{\partial T}{\partial t} = 0, \frac{\partial P}{\partial r} = 0$$

On the surface of cooked beef (12):

$$-\lambda \frac{\partial T}{\partial r} = q_{sf}, P = P_{vc}$$

Where T_0 ——the initial temperature of the product, °C; $P_{sat,}$ 0 ——the saturation pressure corresponding to the initial temperature of the product, Pa; P_{vc} ——the pressure in the vacuum chamber, Pa; q_{sf} ——the heat absorbed by the evaporation of water inside the product per unit area , W / m^2. Its expression (13) is:

$$q_{sf} = \dot{m}_{sf} h_v$$

Where m_{sf} is the evaporation rate of moisture per unit area of cooked beef, kg / (m^2 s). Its expression is (14):

$$\dot{m}_{sf} = h_m (\mathrm{P_{sat}} - P)$$

3. Model Validation

3.1 Materials and Methods

Equations (1), (2), and (5) and the boundary conditions can constitute a non-linear differential equation. Generally, it is difficult to find an analytical solution for this type of equation, so it must be solved by numerical methods. In this paper, the modified CONDUCT program is used to solve the water migration model by finite difference. The model only considers the radial heat transfer and water migration of cooked beef. In the simulation, a cylindrical piece of meat with a diameter of 60 mm and a length of 150 mm was used. During the simulation, the initial temperature of cooked beef was 63 ° C, the initial moisture content was 71%, and the space and time steps were Δr = 2 mm and t = Δ30 s, respectively. The initial physical properties of cooked beef are shown in Table 1. The specific heat capacity and thermal conductivity of cooked beef have a great relationship with their moisture content. The specific heat capacity and thermal conductivity of cooked beef used in this paper are calculated by the following formula.

$$\mathrm{c_p} = 0.837 + 3.3.49W \quad (5)$$

$$\lambda = 0.216 + 0.33W \quad (6)$$

Where W-moisture content in food,%.

Table 1: Physical Parameters in the Water Migration Model During Vacuum Cooling

Model parameter							
Cooked meat density(ρ)/kg/m^3	specific heat (cp)$J/(kg\cdot K)^{-1}$	Heat transfer coefficient (λ)/ $W/(m\cdot K)^{-1}$	Porosity of cooked meat ^{a}(ω)/%	Channel diameter ^{a}(d)/mm	Gas viscosity (η)/Pa·s	Gas density (ρ_g)/$kg\cdot m^{-3}$	latent heat (h_v)/$Kj\cdot kg^{-1}$
1093	3214.8	0.4943	6	2.5	9.62×10^{-6}	0.0512	2791.2

The verification of the moisture migration model was performed by vacuum cooling experiments of cooked beef. The vacuum cooling experimental device is shown in Figure 1. The vacuum cooling experimental device is mainly composed of 4 parts: vacuum chamber, vacuum pump, cold trap and refrigeration system. The samples used in this experiment were deboned pork hind legs, which were purchased directly on the market [12]. Raw meat is heated to a certain temperature in water by RF-P130Y electric heating pan (Zhuhai Gree Electric Appliances). The temperature distribution of cooked beef during the experiment was measured by a T-copper-constantan thermocouple with a measurement accuracy of ± 0.1 °C. The pressure in the vacuum chamber is measured by a CPCA-130Z pressure sensor (Shanghai Zhentai Instrument Co., Ltd.) with an accuracy of ± 1 Pa. The experimental monitoring and data acquisition system uses the industrial automation general configuration software Kingview 5.0 developed by Beijing Yakong Automation Software Technology Co., Ltd. The pressure and temperature data acquisition is achieved through the Newton module I-7018P.

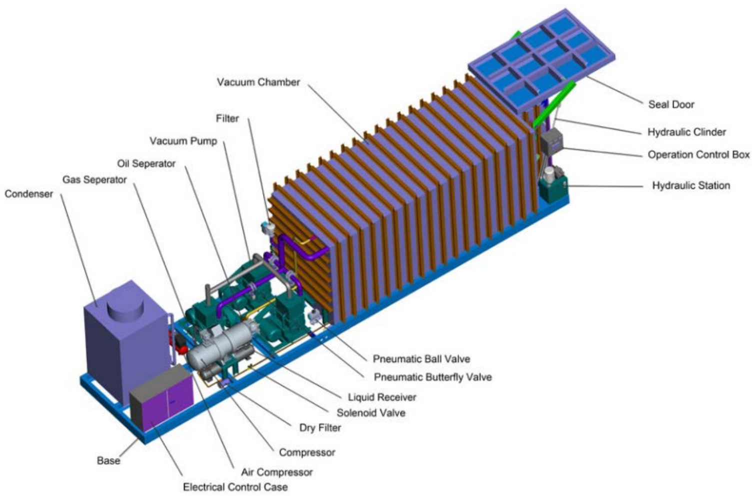

Figure 1. Vacuum Cooling Device for Beef

3.2 Vacuum Cooling

Temperature change at different locations during vacuum cooling. The calculated results agree well with the experimental results, and the maximum error between them is about 5%. Due to the heat conduction inside the cooked beef, there is a certain temperature difference between the surface and the center of the cooked beef during the vacuum cooling process. After the vacuum cooling process is completed, the surface temperature and center temperature of the cooked beef are 3.5 and 7.5 °C, respectively.

During the initial stage of vacuum cooling, the pressure distribution inside the cooked beef is uniform. During vacuum cooling, the pressure change in the vacuum chamber has a significant effect on the pressure distribution inside the cooked beef. The pressure change in the vacuum chamber during the vacuum cooling process, it can be clearly seen that the pressure in the vacuum chamber decreases from atmospheric pressure to 9867 Pa within 2 minutes [13-14]. When the pressure is lower than or equal to the saturation pressure corresponding to the temperature of the cooked beef, the moisture inside the cooked beef will boil. In the non-boiling zone, the temperature distribution of cooked beef is only affected by heat conduction, and the pressure and temperature distribution are parabolic. In the boiling zone, the pressure distribution and temperature distribution affect each other. During the vacuum cooling process, the boiling interface moves along the radial direction of the cooked beef. According to the pressure distribution inside the cooked beef and the pressure change in the vacuum chamber, it can be known that during the vacuum cooling process, the water on the surface of the cooked beef first boils, and the interface is then moved to the center [15]. From the boiling interface to the center of the cooked beef, the water does not boil because the pressure is higher than the saturation pressure corresponding to the temperature of the cooked beef. However, with the rapid decrease of the pressure in the vacuum chamber, the boiling interface moved from the surface of the cooked beef to the center within 2 min.

Figure 2. Vacuum Cooling of Beef

4. Effect of Vacuum Cooling at Different Temperatures on Vacuum Nutrition of Beef

4.1 Effect on Beef Tenderness

Shear force is an important indicator of meat quality and has a positive correlation with beef tenderness. The shearing force of vacuum cooled beef gradually increased with the decrease of temperature; after the negative pressure injection, the shearing force of beef decreased first and then increased to a minimum value at 20 ℃. And the shearing force of vacuum-cooled beef was significantly greater than that of beef after negative pressure injection. The analysis of variance showed that the effect of different processing methods and temperature on the center temperature of beef was significant ($p < 0.05$) [16]. The main reason is that the meat loses a lot of water during the vacuum cooling process, which causes the muscle fibers to contract and harden and increase the shear force. After the negative pressure injection, the moisture content of the beef increases, and the moisture returned to the beef fills the gaps between the muscle fibers, so that the muscle fibers that have contracted and hardened are alleviated, and the shear force is reduced accordingly, thereby improving the tenderness of the beef. degree.

4.2 Effect on Beef Color

The color of the product can give consumers the first sensory impression and directly affect consumers' desire to buy. In this paper, the effect of different processing methods on the color of beef is studied. Color parameters Luminance (L *), redness (a *), and yellowness (b *) are important indicators that reflect the color of the sample. With the decrease of temperature, the brightness value of beef after vacuum cooling-negative pressure injection is lower than that of vacuum cooling beef; the redness value is higher than that of beef after vacuum cooling, showing a trend of increasing first and then decreasing; yellowness value is lower than vacuum After cooling, the beef tends to increase first, then decrease, and then increase. Generally speaking, compared with the beef cooled by vacuum, the analysis of variance shows that the brightness (L *), redness (a *) and yellowness (b *) of the beef after vacuum cooling and negative pressure injection are not Significant difference ($p > 0.05$) [17]. This shows that the vacuum cooling-negative pressure injection method has no obvious effect on the color of beef.

Figure 3. Food Safety

4.3 Impact on Sensory Evaluation of Beef

The comprehensive score of beef under vacuum cooling-negative pressure injection at different temperatures is generally higher than that of beef after vacuum cooling, indicating that the quality of beef after vacuum cooling-negative pressure injection has been significantly improved, and vacuum cooling-negative pressure The comprehensive score of the injection solution at 20 ℃ is the highest, which means the best quality. The effects of the two treatments on color and lustre at different temperatures were not significant, and had an impact on flavor, juicyness, elasticity and taste [18-19]. As the temperature decreased, the scores of beef flavor, juicyness, color and texture after vacuum cooling showed a downward trend, and the elasticity showed an upward trend. The reason may be that with the extension of the vacuum cooling time, the moisture in the beef is getting less and less, which causes the muscle fiber tissue in the beef to become harder and harder, so that the beef's elasticity is gradually increased, while other sensory index scores are It is getting smaller and smaller, and the comprehensive indicators are also showing a downward trend, indicating that as the temperature decreases, the overall quality of beef after vacuum cooling is getting worse and worse [20]. Except for the elasticity of the vacuum-cooled-negative-pressure-injected beef, the scores of other sensory indicators were higher than that of the vacuum-cooled beef, and the reduction of the elasticity index just improved the taste of the beef. Therefore, the vacuum cooling-negative pressure injection solution can improve various indexes of beef and can improve the edible quality of beef.

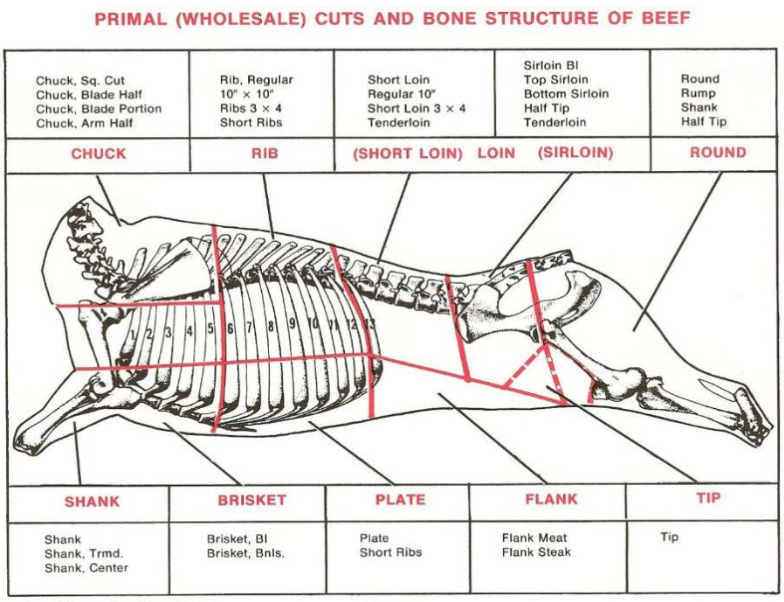

Figure 4. Beef Skeleton Structure

4.4 Effect on Beef pH

Theoretically, increasing the pH will cause the myofibril protein to deviate from its isoelectric point, and the net negative charge of the protein will be more, which strengthens the interaction between the protein and water, and weakens the interaction between the protein and the protein. Sufficient, high water retention. After vacuum cooling and negative pressure injection, the pH of beef increased first and then decreased with the decrease of temperature, but the difference was not significant and not significant (P > 0.05). After vacuum cooling, the pH of beef gradually increased with the decrease of temperature, but the difference was not significant and not significant (P > 0.05). By comparing the overall trend of the pH value of beef obtained by vacuum cooling-negative pressure injection and vacuum cooling, it can be seen that the pH after negative pressure injection is generally higher than that of vacuum cooling, and the difference is significant. (P <0.05) [21-22]. This shows that the pH value of the vacuum cooling-negative pressure liquid injection treatment deviates more from the isoelectric point, and the beef has greater water holding capacity and stronger water holding capacity. It can be further concluded that, compared with vacuum cooling, vacuum cooling-negative pressure injection can effectively increase the water retention of beef and enhance the water retention of beef.

5. Conclusion

This paper mainly studies the mechanism of water migration during vacuum cooling, and establishes a mathematical model of water migration during vacuum cooling. This model can predict the temperature and pressure distribution inside the product during vacuum cooling. Because the internal pressure of cooked beef cannot be tested, only the temperature of the product can be verified. Through experimental verification, the temperature simulation results are basically consistent with the experimental results, with the maximum error within 5%. From the changes in moisture content and water evaporation rate of cooked beef and the temperature and pressure distribution of cooked beef during the vacuum cooling process, the following conclusions can be drawn: The pressure difference between the inside of the cooked beef and between the cooked beef and the vacuum chamber is the moisture during the vacuum cooling The main driver of migration. The direction of water migration is mainly along the radial direction, and it is mainly migrated outward in the form of steam. With the progress of the vacuum cooling process, the boiling interface moves from the surface of the cooked beef to the center. With the rapid decrease of the pressure in the vacuum chamber, the boiling interface moves from the surface of the cooked beef to the center within 2 minutes. Because not only the weight is lost in the vacuum cooling process, but also the flavor of the product, some water-soluble flavor substances are also lost with the evaporation of the internal moisture of the product, thereby reducing the product quality. By selecting the liquid injected under negative pressure, it can not only make up for the quality loss in the vacuum cooling process, but also make up for and increase the flavor of the product and improve the product quality. From a nutritional point of view and taste, after vacuum cooling-negative pressure injection, the comprehensive score of beef at 20 ° C was the highest, and the food quality was the best. Taken together, the optimal vacuum cooling temperature is 20 ° C. At this time, the rehydration rate is the largest and the food quality is the best.

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