

Image Analysis on Temperature Distribution within Lettuce Undergoing Vacuum Cooling

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ABSTRACT

Measurement of temperature within the products undergoing vacuum cooling is one of the key issues, especially if to be used as a control parameter in the cooling process. Thorough study on temperature distribution during the cooling process is indispensable in order to precisely determine the appropriate location of temperature measurement within the product being vacuum-cooled. This experiment is aimed to utilize an image analyzing procedure for studying temperature distribution within a head lettuce and its expansion during vacuum cooling process.

The study shows that temperature in the cross-sectional surface of the product, which was initially uniformly distributed, was begun to propagate towards non-uniformity at the flash point. The non-uniform temperature distribution was expanded to reach its maximum when the chamber pressure reach the controlled minimum level, and rebound down toward a uniform distribution afterwards. A modified mass-average-temperature analysis was used to precisely determine the appropriate location of temperature measurement within the product during the vacuum cooling process.

Keywords: precooling, thermograph, image processing, mass average temperature

1. INTRODUCTION

1.1 Background

Vacuum cooling is a popular method in precooling of leafy vegetables for its acknowledged fast cooling rate and uniform temperature distribution (Anjo, 1991, Nakajima et al., 1992). Nevertheless, the uniform temperature distribution is not obtained spontaneously during the cooling process. This condition is especially profound during vacuum cooling of vegetables with tightly heaped leaves, such as lettuce.

Propagation of temperature and moisture content distribution and their progress toward the uniform condition at the end of the cooling process is indispensably important for thorough analysis of the heat and mass transport mechanism and determination of optimal vacuum cooling process. The temperature distribution history can be used to determine the precise location of temperature measurement within the product during the cooling process. Controlling the vacuum cooling process using temperature measured at the precise location is indispensable to avoid freezing or chilling injury at some portion of the product while insufficiently cooled at other portions (Nakajima, et al., 1992).

Temperature reduction during vacuum cooling process is closely related to the evaporation of water from the product. Thereby, temperature gradient within the product could also affect uniformity of its moisture content. This condition may induce excessive moisture loss from the outer layer of the product and yield in partial wilting. Aside from injuring the product quality, imprecisely determination of the temperature measurement point can downgrade the vacuum cooling efficiency. Insertion of thermocouple probe for measuring inner temperature of the product during the process is perplexing due to water evaporation at the opened hole, which making uncertainty in the measured value. Utilization of thermograph to detect the temperature can avoid the uncertainty, besides its availability for surface temperature analysis using the image analyzing method.

1.2 Objectives

The objectives of this experiment are:

- (1) To study the temperature profile within lettuce undergoing vacuum cooling using the thermograph and image analyzer.
- (2) To determine the optimum location for temperature measurement in the product during vacuum cooling process.

2. EXPERIMENT METHOD

Lettuce was used as the cooling object due to its leaf structure. The internal temperature profile during the vacuum cooling process was measured using a thermograph (Figure 1) as well as thermocouple probes (type T, diameter 0.1 mm). Upon consideration on factors affecting cooling rate of lettuce (Haas and Gur, 1987), the vacuum cooling operating condition was controlled at 0.8 kPa in minimum chamber pressure and -9° C in coldtrap temperature. This operating condition was adopted to avoid possibility of freezing and chilling injure in the product, which may affect the temperature and moisture content distribution.

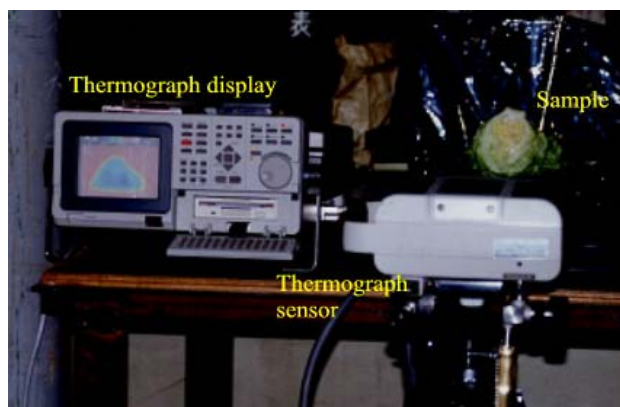


Figure 1. Thermograph set up

Temperature measurement by the thermograph was performed 5 times during one cycle of the process, namely at the beginning and the end of each four periods. The first period (A) was the time needed for air evacuation from the chamber to reach the minimum pressure, while the second (B), the third (C), and the fourth (D) respectively were 10, 15, and 20 minutes elapsed cooling time of the cooling process. Thermograph is an instrument

commonly used to indicate the distribution of temperature across a surface, applying radiation emissivity of the body as its sensing parameter. Emissivity of the lettuce was assumed equal to 0.99 in this experiment. Data detected by the thermograph was stored in a floppy disc in form of gray scale, which was divided into 256 sliced-level. The temperature profile could be displayed and printed in 16 color-levels, where each color-level represents 16 sliced-level of the gray scale. Those data was analyzed with a Personal Image-data Analyzer System (PIAS LA-500). During each period, temperature was also continuously measured using thermocouple probes at 4 places, namely the outer leaves (within 2.5 cm from surface), inner leaves (2.5 – 5 cm) and core (within 5 cm to the core). The changes in chamber pressure and the product's mass were measured continuously during each of the period.

Upon termination of the cooling process at each period, the product was cut in half from its butt. One half of the product was used for moisture content determination, while another half was used for measurement of the temperature distribution using the thermograph. The moisture content was determined by oven method with temperature of 100 °C in 3 hours. Preliminary experiment showed that this temperature-time condition is the most optimal one for determination of lettuce's moisture content. The experiment was performed for there is no precise standard for moisture content determination of lettuce using oven method.

3. RESULTS AND DISCUSSION

3.1 Internal Temperature Profile

The initial temperature distribution within the lettuce cross-section was recorded with the thermograph, and analyzed with the Personal Image Analyzer System, is presented in Figure 2. Temperature scale is attached on the upper side of the figure, where each color-level was fixed to 0.8° C of temperature width. The figure indicates uniformity of the temperature within the product before the vacuum cooling process was performed. Referring to the figure, the average initial temperature of the lettuce was 16.2° C.

The internal temperature distribution of lettuce during each cooling period as recorded by the thermograph is shown in Figure 3. The figure shows a higher temperature at the most outer layer of the product compared with the inner ones, which was imposed by the edge effect. Edge effect is temperature bias detected by the thermograph due to the abrupt change in geometrical shape at the boundary between the product and the surrounding air. Since thermograph detects heat emission, shape factor of the body being measured will naturally affect the value. Upon elimination the edge effect, temperature distribution inside the lettuce presented in both figures indicate that temperature gradient inside the lettuce head was commenced and began to propagate after the flash point. The temperature was lower at outer portions, followed by inner portions, and higher at the core. The corresponding temperature distribution as recorded by the thermocouple showed the same configuration.

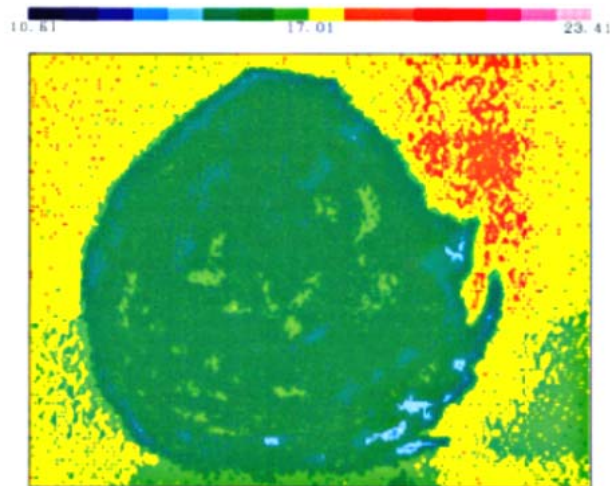


Figure 2. Thermograph data of the initial temperature

Propagation of the temperature gradient was apparently caused by the slower cooling rate at the inner leaves compared to the outer ones. According to the kinetic theory of gas, the driving force for evaporation is the difference between saturation pressure of the water molecules and vapor pressure of the surrounding. When the vacuum chamber reached the saturation pressure corresponds to the product temperature, water molecules on the surface, which is directly exposed to the vacuum condition, evaporated at the first place and thereby cooled down firstly (Tambunan, et al., 1993). Water molecules within the inner tissues evaporate with slower rate, and are most probably cooled down by heat conduction to the outer ones.

Overlapping leaves, such as in lettuce, may generate resistance to air and water vapor removal from the intervening spaces. The resistance is larger at the inner portion of the leaves heap and yields in vapor pressure gradient within the product. The smaller pressure difference yields in slower evaporation rate, and accordingly generates gradient of temperature within the product being vacuum cooled. During the controlled minimum pressure periods (B, C and D period) of the vacuum cooling process, the temperature gradient come closer to one another and become more uniform at the end of the cooling process.

Evaluation on moisture content distribution of the sample showed that the initial moisture content of outer portion was higher than others but significantly lower after the flash point. The lower moisture content of the outer portion was continued until cooling time elapsed 10 minutes (B period). After 15 and 20 minutes elapsed cooling time, moisture content of the outer and inner portions became more uniform than before. This fact consistent with the change in temperature distribution explained above, and confirmed the higher evaporation rate of water from outer portion of the product.

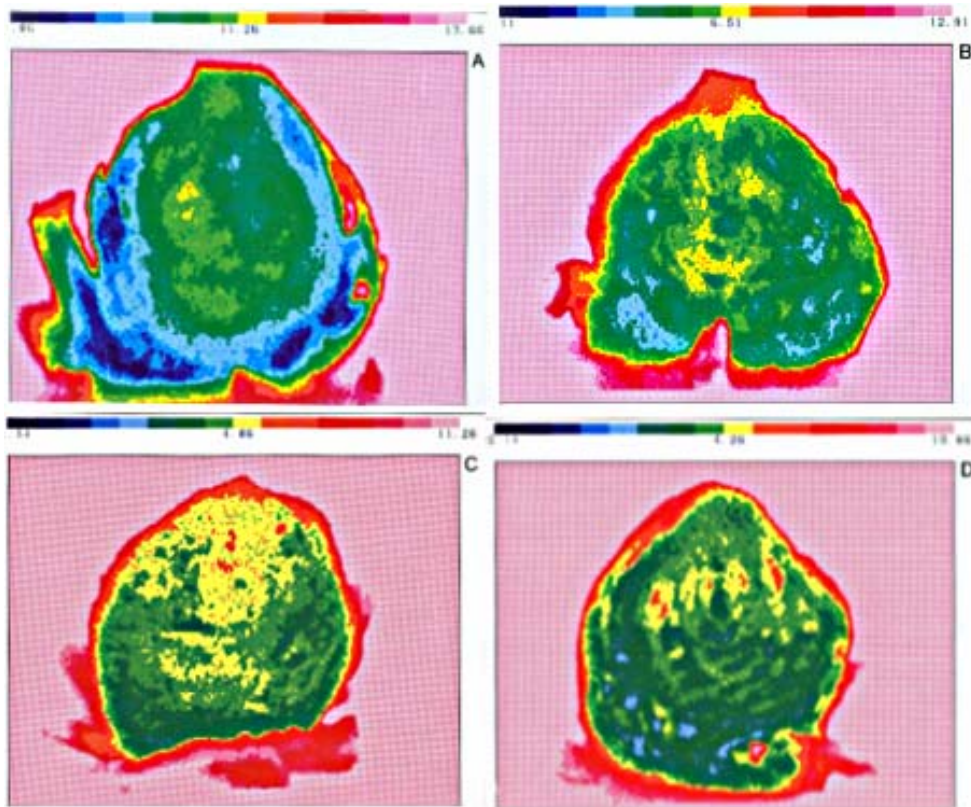


Figure 3. Thermal images of the temperature distribution changes at each period

3.2 Mass-Average Temperatures and Location

A mass-average temperature is defined as a single value, which indicates temperature of a product when its temperature distribution would become uniform under adiabatic conditions. In a transient cooling process the mass-average temperature is a useful indicator in discussing the cooling effect and determining a representative single temperature of the temperature distribution at any time of the cooling process. Even though the concept of mass-average temperature is commonly used to analyze temperature gradient generated by heat conduction within a solid body, it is worth to try its applicability to predict the progress of vacuum cooling and the existence of temperature gradient within the product as well as its alteration towards uniformity at the end of the process.

Mass-average temperature of a spherical body is presented mathematically by (Tambunan, 1993),

$$T_{ma}^* = \frac{\int T^* dm}{\int dm} \quad (1)$$

where T^* is non-dimensional temperature defined as the ratio of local temperature of the product to its initial temperature (T/T_1), dm is differential mass of the product, and T_{ma}^* is the non-dimensional mass average temperature. Assuming the sample as a spherical body (Figure 4), the local temperature on its cross sectional surface is determined in terms of its radius and

angle from a vertical axis passing through the butt. The butt temperature was not considered in this analysis for it has a different temperature from other portions of the lettuce, as is found also by Aimin, et al. (1999) when studying vacuum cooling of Chinese cabbage and Chinese kale.

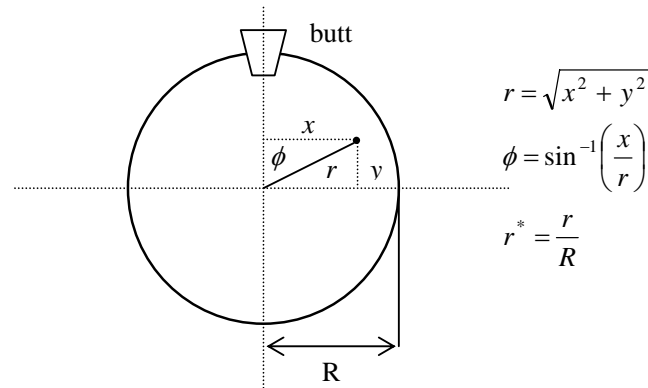


Figure 4. Geometrical definition of radius and angle within the sample

By image analysis on the thermograph data, a polynomial regression model was constructed to represent the local temperature in terms of both variables, such as in equation (2).

$$T^* = b_0 + b_1 r^* + b_2 \phi + b_3 r^2 + b_4 \phi^2 + b_5 r \phi \quad (2)$$

Here, r^* is the non-dimensional radius defined as the ratio between the distance of a point from center (r) and the overall radius of the body (R), while ϕ is the angle position of the point. Differential mass of the spherical body can be defined as,

$$dm = 2\rho R^3 r^{*2} dr^* d\phi \quad (3)$$

Here ρ is the product density. Substitution of equation (2) and (3) into equation (1), and integration in respect to r^* and ϕ , gives the mass average temperature in terms of the polynomial coefficients, as follows,

$$T^*_{ma} = b_0 + \frac{3}{4}b_1 + \pi b_2 + \frac{3}{5}b_3 + \frac{4}{3}\pi^2 b_4 + \frac{3}{4}\pi b_5 \quad (4)$$

Those coefficients were determined by analyzing the image data obtained from the thermograph after eliminating the edge effect, using least square method. Verification of the coefficient by statistical F-test and interaction between each variable by student-t test confirmed the validity of the model. Using the polynomial, the mass-average temperatures at each period can be calculated as presented in Table 1, which indicate a decreasing mass-average temperature according to the elapsed time of the vacuum cooling process. The table also shows that wrapping of the product during vacuum cooling gave no significant difference to the mass-average temperature of the product, provided that there is enough opening at the wrapping material to allow air evacuation from its inner side.

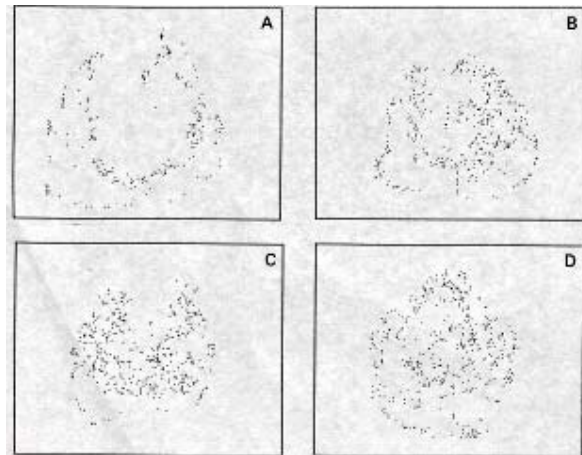


Figure 5. Location of the mass-average temperature within the sample cross-section.

Table 1. Mass-average temperature of lettuce under going vacuum cooling

Conditions	Cooling period	Mass-average temperature (°C)
Bare lettuce	A (flashing)	10.2
	B (10 minutes)	6.1
	C (15 minutes)	5.4
	D (20 minutes)	2.9
Wrapped lettuce	A (flashing)	10.2
	B (10 minutes)	6.2
	C (15 minutes)	5.1
	D (20 minutes)	2.6

The image data analyzer was also used to locate the position of the mass average temperature within the cross sectional surface of the sample, using the calculated value. The results for experiment on bare lettuce are illustrated in Figure 5. The figure indicates that the location of the mass-average temperature after the cooling period A is identifiable, but distributed evenly through out the cross-sectional surface afterwards. The indefinite location of the mass-average temperature indicates the uniform temperature distribution of the sample. Accordingly, determination of the precise location of temperature measurement is most important during the initial periods of the vacuum cooling process. Experiments on wrapped lettuce gave the same configuration with those of bare lettuce, showed no significant influence of wrapping to the vacuum cooling process.

4. CONCLUSIONS

1. Distribution of the sample's internal temperature distribution was propagating after the flash point until the minimum chamber pressure was reached, but rebounded to a uniform temperature afterwards
2. Determination of the precise location for temperature measurement during the initial stages is indispensably important in order to optimally control the chamber pressure and avoid the possible freezing or chilling injure of the product.

5. REFERENCES

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