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Investigation of total emissivity of pistachio kernel using thermal imaging technique

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Emissivity is an important parameter to determine the temperature of agricultural materials and also to manage some of agricultural engineering operations using thermal imaging (TI) technology. The goal of this research was determination of the total emissivity of pistachio kernel, as a necessity for non-contact thermometry, and investigating the influence of surface temperature and moisture content of pistachio kernel on that. Thermal imaging camera and contact thermometer were used and theire readings were compared for these purposes. The total emissivity of pistachio kernel in 4.5% moisture content was obtained 0.95. The results showed that the total emissivity of pistachio kernel increased by increasing of temperature and decreasing of moisture content.

Key words: Emissivity; Non-contact thermometry; Thermal Imaging Technique; Pistachio; Temperature; Moisture Content.

Introduction

Agricultural engineering requires new and advanced technologies in order to carry out rapid, in-time, and low-cost different agricultural engineering operations. In this regard, agricultural automation is an important auxiliary to reach these purposes. One of the significant techniques in agricultural automation is thermometry.

Non-contact thermometry is a method that determins material surface temperature without any contact with the objects. This method has higher speed and more application than contact thermometry. The new technique that used in this method is thermal imaging (TI). Thermal imaging technique has vast applications beyond the surface temperature determination, such as nondestructive assessing of food quality and reliability in food industries. In

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this regard, researchers reviewed application of this technique in different operations in agricultural engineering (Manickavasagan *et al*., 2005, Gowen *et al*., 2010; Kheiralipour *et al*., 2011).

Eq. (1) shows fundamental concept of thermal imaging technique in wavelengths from 8 to12 µm:

$$W=\varepsilon*\sigma*T^{4.5} \quad (1) \text{ (Gowen } et\ al., 2010)$$

Where, W is the energy emitted from the target (W/m^2), ε is the emissivity of the target, σ is the Stefan-Boltzmann constant (5.67×10^{-8}Wm^{-2} K^{-4}) and T is the surface temperature of the target (K) (Gowen *et al*., 2010).

In the technique, a thermal imaging camera measures the W and then produces a thermogram using Eq (1). Thermogram is a pseudo-image of the target representing its surface temperature. As seen in Eq (1), the emissivity of the target must be known.

The emissivity of material is a coefficient that shows the ratio of its radiated energy to that of black body at the same temperature. Emissivity specifies the amount of lost or gained thermal radiation by a target (Anonymous, 2011a). As mentioned above, this coefficient is an important parameter for non-contact determination of surface temperature (i.e. using thermal imaging cameras).

There are two types of emissivity; wavelength-dependent or spectral emissivity and hemispherical or total emissivity. For non-contact determination of material temperature the spectral emissivity must be known. There was assumed that wavelength has not effect on surface's spectral emissivity, so that the emissivity assumed as a constant. But, to determine heat transfer, the total emissivity should be measured. In this case, surface emission in only a particular direction and a particular wavelength was considered (Anonymous, 2011a).

The emissivity coefficient depends on surface temperature (Dlaverty, 2009). As can be seen in fig. 1 the surface at higher temperatures radiate than thermal energy.

Also, emission angle and wavelength that received by a camera has affected on the emissivity. According to fig. 1, the maximum IR radiation is obtained in a specific wavelength. The emissivity of a material depends on its thickness. There was told that thinner materials have lower emisivities. But, in general utilities, the emissivity was measured assuming infinite thickness for targets.

There were emissivity tables exist in different books and references for different materials (Anonymous, 2011b & c). As seen in these tables, the emissivity of materials differs from each other. This fact shows the effect of material surface on its emissivity. Surface parameters such as moisture content, color and roughness have effect on the emissivity.

As mentioned above, there are emissivity tables for different materials, but there aren't such tables for agricultural materials. And also no papers were published regard to determination of the emissivity of agricultural materials. So, this research was conducted to investigate on non-contact thermometry of pistachio kernel. In this regard, the emissivity of pistachio that is essential for non-contact thermometry was studied. Also, the influences of surface temperature and moisture content of pistachio kernel on its emissivity were investigated.

Materials and methods

This research was performed in Mechanical Engineering of Agricultural Machinery Dept, University of Tehran, Karaj, Iran.

Materials

Pistachio kernels required in the present research were randomly selected from Akbari variety of Rafsanjan region, Kerman, Iran. ULIRvision TI160 thermal imaging camera (Zhejiang ULIRvision Technology Co, Zhejiang, China), for non-contact thermometry, and 4 Channels K/J type Thermometer, (LTD Co, Taiwan) for contact thermometry, of pistachios were used. Fig. 2 shows the thermograms of pistachio in different temperatures, obtained by the thermal imaging camera. As shown in this figure, pistachio was fixed by a plastic clamp to avoid the effect of human hand on pistachio temperature. The distance between the camera and sample was set as 10 cm.

Emissivity Determination

The first step was done to determine emissivity of the pistachio kernels. In this step, the thermal imaging camera readings were recorded in different emisivities (from 0.01-1).

Effect of Moisture Content on Emissivity

In the second step, the effect of moisture content on the pistachio emissivity was investigated. In this regard, two moisture content levels were considered; dried and artificially moistened samples. The moisture content for dried and moistened pistachio samples were determined that they were 4.5% and 80.5 %, respectively, using oven method.

The temperature of pistachio in different moisture content levels was measured by both thermal imaging camera and contact thermometer. The difference of two readings was plotted against pistachio moisture content.

Effect of Surface Temperature on Emissivity

In the third step, the effect of pistachio temperature on its emissivity was studied. The temperature of pistachio in different temperatures was determined. Three pistachio thermograms have been shown in fig. 3.

Analysis

To determine the emissivity of pistachio kernel, the thermal imaging camera readings were plotted versus emissivity. The difference of two thermometers' readings was plotted against pistachio temperature and pistachio moisture content, individually, using Microsoft Excel Worksheet and MATLAB 2009A software.

Results and discussions

Recorded temperature obtained by the thermal imaging camera was plotted versus emissivity of pistachio from 0.01 to 1 (Fig. 4). The surface temperature of pistachio kernel recorded by the contact thermometer was around 26.5 ºC. When the emissivity was set near zero, the recorded surface temperature has had highest values. As shown in fig. 4, the low the emissivity, the high the surface temperature was recorded by the camera. ~~The~~ By increasing of the emissivity, the recorded temperature by the camera will close be to that recorded by the contact thermometer.

As a result, the data in Fig. 5 is similar to Fig. 4 but with lower variation of emissivity (0.9-1). By closely observation of this diagram, it could be seen that when the emissivity is 0.95 the temperature had lowest value (around 29.5 ºC). In this time, the deference between the temperature recorded by the camera and that of contact thermometer was lowest (around 3 ºC). Chelladurai *et al.* (2010) considered 0.98 as emissivity of wheat kernel to specify its fungal infection (Chelladurai *et al.*, 2010).

Effect of temperature and moisture content on temperature difference (i.e. recorded temperature by the thermal imaging camera minus corresponding values measured by the contact thermometer) and subsequently emissivity of studied pistachio was fitted in a surface as shown in Fig. 6.

The temperature difference versus moisture content of pistachio kernels (in 2 levels) was plotted in Fig. 7. Here, it can be seen that by increasing of moisture content, the emissivity would be decreased. Because, according to Fig. 4, when the emissivity set lower the temperature was over estimated. To avoid this, the emissivity must be increased. So, emissivity must be decreased to correct reading of the camera in Fig. 7. This result is due to low emissivity of water. The emissivity of water in 37 ºC is 0.67 (Anonymous, 2011c). This amount is lower than emissivity of pistachio. So, the emissivity will be reduced by increasing of moisture content.

The variation of temperature difference between two thermometers versus temperature of pistachio kernel in 4 levels has been presented in Fig. 8. This diagram has an inverse trend compare to Fig. 7. So, it can be explained that increase of temperature will increase the emissivity of pistachio. This result was in agreement with Fig. 1.

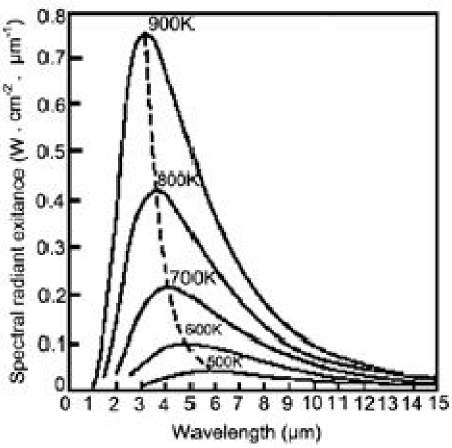

Fig. 1. Effect of temperature and wavelength on emissivity (INMES 2011)

Fig. 2. ULIRVision TI160 thermal imaging camera

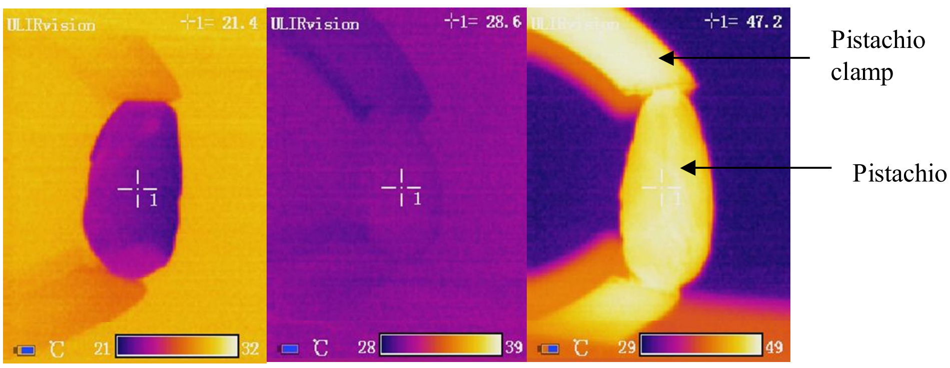

Fig. 3. The thermogram of pistachio kernel in different temperatures

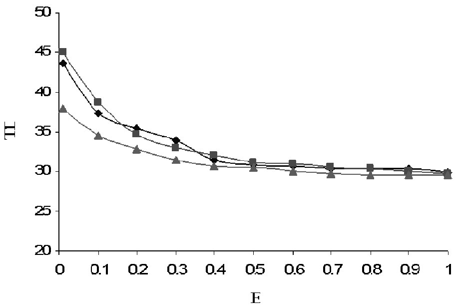

Fig. 4. Recorded temperatures versus emissivity of pistachio (0.01-1)

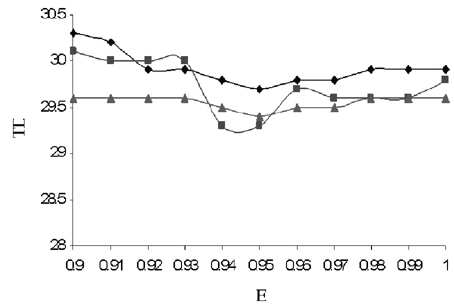

Fig. 5. Recorded temperatures versus emissivity of pistachio (0.9-1)

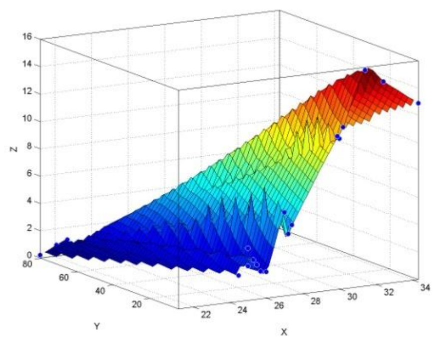

Fig. 6. The surface of the difference of contact and non-contact thermometry (Z), moisture content (Y) and temperature (X)

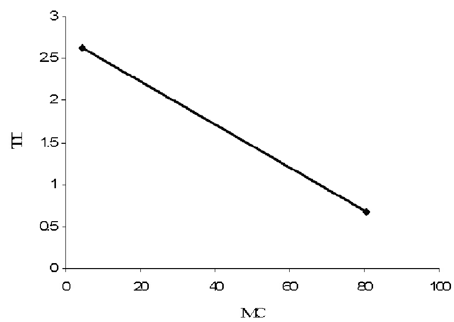

Fig. 7. The difference of contact and non-contact thermometry (TD) against moisture content of pistachio (MC)

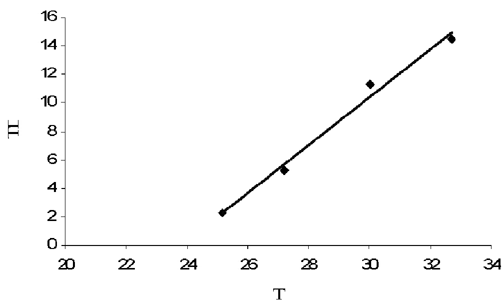

Fig. 8. The difference of contact and non-contact thermometry (TD) against temperature of pistachio (T)

Conclosions

The emissivity of pistachio in 4.5% moisture content was 0.95. The emissivity of pistachio will be increased by increasing of its surface temperature. Compare to pistachio temperature, moisture content has reverse relationship with emissivity. The authors recommend more studies on emissivity of other agricultural materials. Another recommendation was concluded from Fig. 6, that one can estimate the moisture content of pistachio using thermal imaging camera.

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