Heat Transfer Convection in The Cooking of Apple Using a Solar Cooker Box-Type

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Abstract. In this work, experimental results to determine the convection heat transfer coefficient in the cooking process of apple using a solar cooker box-type are presented. Experimental data of temperatures for water, surface and central point of the apple were used. To determine the convection coefficient, the apple was modelled as a sphere. The temperatures evolution was defined using thermocouples located at water, surface and central point in the vegetables. Using heat transfer convection equations in transitory state and the temperatures measured, the Biot number and the convection coefficient were determined.

1. Introduction
For many applications in different areas the convection heat transfer coefficient must be determined for different proposes. Due to this, the variety of cases is big, such as next is exposing.

The external heat transfer coefficient in steam processing was determined experimentally in a pilot scale. Using the finite element method, heat transfer equations were established and solved. The actual retort temperature profile were used as boundary conditions. To analyse the time-variability along a retort cycle, the heat transfer coefficient values were determined for various instants [1].

In foods and liquids like beverages, the cooling and freezing times are required. For this purpose, the design of food refrigeration equipment are necessary. Also, refrigeration loads are required. Using the surface heat transfer coefficient for the freezing or cooling operation the refrigeration loads can be estimated. For this purpose, heat transfer coefficients from cooling curves were obtained by means of a iterative algorithm. For various food items heat transfer coefficients were determined [2].

In an experimental study for potato, the heat transfer properties in terms of its convective heat transfer coefficient were calculated. For potato cylinders drying experiments were performed. The convective heat transfer coefficient was evaluated for combined effects of heat capacities in food products. According results the convective heat transfer coefficient for potato cylinders was varying from 11.73 to 16.23 W/m² °C [3].

A rectangular metal tank filled with an alcoholic solution was used to determine the spatial distribution of h values inside tunnels. As a model system, a temperature sensor inserted in its interior was implemented. The h values for different positions inside the tunnels were calculated. The experimental method itself is the main result, due to it is reproducible to determining heat transfer coefficients inside industrial tunnels [4].
In the food preservation, the thermal processing is very useful due to its easy methodology. In this case, steam, air or water are used and the convective heat transfer coefficient must be determined. For this reason, a method to determine the convective heat transfer coefficient was implemented for thermal process of foods [5].

In an article, the behaviour of heat and mass transfer relation during khoa making was investigated. Considering a thermal model to estimate the maximum evaporation during heating of milk, indoor experiments were done. It was observed that with the varying voltage, the convective and evaporative heat transfer coefficients decrease when the rate of heating is increased. It was also observed that when the operating temperature is increased, the convective and evaporative heat transfer coefficients also are increased. The rate of increment of evaporative heat transfer coefficient was higher than the convective heat transfer coefficient [6].

In this work experimental results for the convection heat transfer coefficient for apple are presented. Agree to results, the highest value to the convection coefficient is 90 W/m² °C for a specific solar radiation of 1150 W/m². The results obtained can be useful in numerical simulation when an estimation for heat convection coefficient is required.

2. Experimental procedure

In the experimental procedure, a solar cooker box-type was used. The solar cooker is integrated by the following elements: 1. a cover with two flat glasses with a clearance between them. 2. Reflectors placed on the cover outer of the cooker 3. Internal reflectors made in commercial aluminium paper placed to different tilt angles, 4. Thermal insulator placed in the lateral part of the same one, and 5. Recipient contains the product to cook. The solar cooker is locked tightly; this allows reaching considerable temperatures in the water. In figure 1 the solar cooker is shown.

![Figure 1: Solar cooker box-type: with exterior reflectors and interior reflectors](image-url)

The solar radiation (total) was measured using an Eppley piranometer model 8-48. Multimeters were used to measure the temperature. Thermocouples k-type at surface, central point of the apple and water were placed. For the tests the temperature was measured each 5 minutes. The interval for the time cooking process was 2.5 hours. The average value of the mass for the eggplant was 250 g and the average value for the water was 250 ml. In figure 2, temperature data measured for apple after to the experimental procedure are shown. This data were selected among ten experimental tests. In all cases, the behavior was similar.
3. Convection coefficients results

When the temperature data is obtained, heat transfer equations are used to determine the convection heat transfer coefficient. Some considerations for this purpose were done: 1. Thermal conductivity constant. 2. One-dimensional flow. 3. Without heat generation. 4. Spherical coordinates. Agree to data measured, is possible to determine the temperatures difference ratio in function of water, surface and center by using [7]

\[ \theta = \frac{T_0 - T_\infty}{T_i - T_\infty} \] (1)

This equation is related with correlations. The reference to determine the convection heat transfer coefficient is [8]

\[ \theta = A_1 e^{-\frac{A_1^2}{F_0}} \] (2)

Where \( A_1 \) and \( I_1 \) must be determined by using tables. Biot number (Bi) and the Fourier number (Fo) are defined as

\[ F_0 = \frac{at}{D^2} \] (3)

\[ Bi = \frac{hD}{k} \] (4)

The Biot number is unknown, for this reason an iterative method is used to determine \( A_1 \) and \( I_1 \). Finally, the convection heat transfer coefficient can be determined solving for \( h \). So, when equation 1 is determined, equations 2 and 4 can be solved for Bi. After this, \( h \) can be calculated by using equation 4. This procedure is applied for all the time during the cooking process.

In figure 3, results for the Biot number corresponding to apple are shown and the convection heat transfer coefficient values for apple are shown in figure 4.

Figure 2 Experimental temperatures for the apple
4. Discussion
Agree to results, temperatures follow next behavior $T_f > T_s > T_c$ (fluid, surface and center respectively) for all cases. This is consistent for the heating process. The difference temperatures between surface and center inside the apple were approximate 0.06.

The temperature inside of the apple was $88.9 \, ^\circ C$ which is enough to reach a complete cooking in the same ones.

**Figure 3** Experimental results for Biot number

**Figure 4** Experimental results for $h$, convection heat transfer coefficient
The maximum Biot value was 3.86. This value indicates that the conduction resistance is greater than the convection resistance for the apple. The convection heat transfer coefficient value was 87.47 W/m² °C.

5. Conclusion
An experimental procedure to determine the convection heat transfer coefficient was exposed. The results show how the convection happens in the heating process for apple. The resistance values are useful, because it allows identify what is the most important thermal resistance in the heating process for apple in their heating process using a solar cooker. The convection coefficient can be used in numerical simulation, particularly, in solar energy applications due to this information is unknown and there is not works about it.

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