THERMOPHYSICAL PROPERTIES ESTIMATION OF MILK USING FLASH METHOD

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Abstract. *During processing, all dairy products are heated and cooled. In order to analyze accurately the rate and amount of heat transfer involved, thermal properties of the products being processed must be known. There are many factors which may affect the thermophysical properties of foods and food products, e.g., composition, density, porosity, product temperature, heat treatment and other details of the particular substance. Recently, transient techniques have become the preferable way for measuring thermal properties of materials. In this work, the laser flash technique is employed in the experimental determination of thermal diffusivity of some dairy products. In this method, the front surface of a small sample is subjected to a short burst of radiant thermal energy. In this paper, tests were made for the identification of thermophysical properties of some dairy products. The NETZSCH LFA 457 MicroFlash, of LES/UFPB was used for measurement and mathematical modeling of transient heat transfer was done numerically using finite difference method. The results obtained for thermal diffusivity, thermal conductivity and specific heat show good agreement with the values available in the literature.*

Keywords*: Flash method, thermophysical property, dairy products, finite difference method.*

1. INTRODUCTION

Thermal processing of food products, ranging from mild to relatively severe treatments, is a common operation in the food industry, where physical modifications affecting the structure and stability of the final product are achieved, mainly to preserve its quality and prevent deterioration. The knowledge of engineering properties, such as density, specific heat, thermal diffusivity and thermal conductivity, as well as the flow characteristics and the heat transfer behavior of food processing fluids is very important for the proper design of industrial plants, definition of levels, product quality and control of manufacturing processes (Afonso *et al*., 2003).

Thermophysical properties (specific heat, thermal conductivity, thermal diffusivity and density) of food are important parameters in describing various thermal processes, optimizing the design and the operation of heating, cooking, freezing and cooling systems (Marcotte *et al*., 2008).

In 1961, Parker *et al*. published their pioneering work on the development of a method for the thermal diffusivity identification of solid materials. Although not specifically devised to, the proposed method also permits the identification of the specific heat of materials. In the method developed by Parker *et al*. (1961), a small and thin specimen is subjected to a high intensity short-duration radiant energy pulse (Pinto *et al*., 2006).

The pulse energy is absorbed on the front surface of the specimen and the resulting rear surface temperature rise is recorded. Parker *et al*. (1961) calculated the thermal diffusivity value from the specimen thickness and from the time required for the rear surface temperature rise to reach 50% of its maximum value ($t_{0,5}$). Generally, the temperature rise in the specimen is small, so that the physical properties can be assumed constant during the test.

Therefore, if the thermal diffusivity of the specimen is to be determined over a temperature range, the test procedure must be repeated at each temperature of interest. Parker *et al*. (1961) named their test procedure as Flash Method. Such method is particularly advantageous because of the simple specimen geometry, small specimen size requirements, rapidity of measurement and handling, with a single apparatus, of materials having a wide range of thermal diffusivity values over a large temperature range. In order to obtain the thermal diffusivity from $t_{0,5}$, Parker *et al*.(1961) used a one-dimensional heat conduction model, neglecting heat losses and assuming that the energy input was instantly deposited within a small depth of the specimen.

The Micro Flash Netzsch model LFA 457 is an instrument used to estimate thermal diffusivity, specific heat and thermal conductivity of metals, graphite coatings, composites, ceramics, polymers, liquids and other materials, using a 25 - 1100°C temperature range based Flash method. The thermal diffusivity of dairy products was determined directly in the Micro Flash Netzsch model LFA 457 for a temperature range of 20 - 60º C.

In this paper, the laser flash technique is used to estimate experimentally the thermal diffusivity, specific heat and thermal conductivity of dairy products using an equipment model NETZSCH LFA 457 Micro Flash.

2. PROBLEM FORMULATION

The direct physical problem is to determine the theoretical distribution of the temperature of a sample of 3-layers when subjected to a Flash experience to estimate the thermal diffusivity of samples of milk products. The experiment consists in confining the sample between two layers of the same metal and submits them to a disturbance through a thermal pulse of short duration in a face and record the temperature change on the opposite side. The physical system is treated as a problem of one-dimensional, multilayer, transient heat conduction. We can see the outline of the aluminum cap, containing the test sample in Figure (1) below.

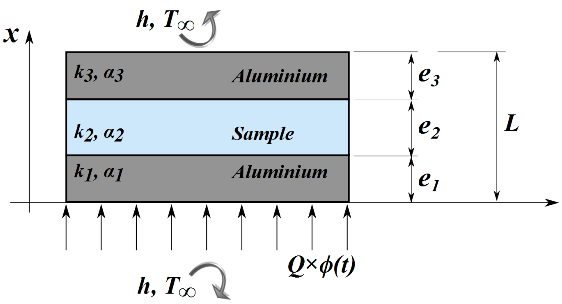

Figure 1. Representation of the physical model

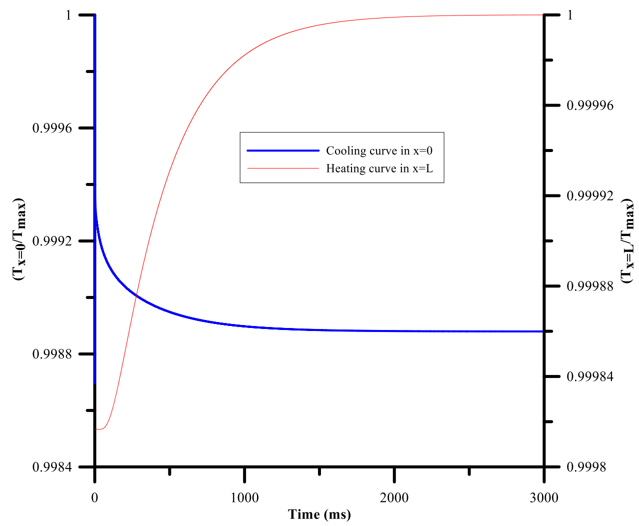

Figure 2. Transient evolution of the temperature in the anterior and posterior surfaces of the sample

The numerical determination of transient temperature distribution is obtained by writing the energy conservation equation appropriately for each of the finite difference temperature nodal points, including the rear surface:

$$\frac{\partial T_i}{\partial t} = \alpha_i \frac{\partial^2 T_i}{\partial x^2}, \qquad 0 < x < x_i, \quad i = 1, 2, 3 \tag{1}$$

$$-k_1 \frac{\partial T_1}{\partial x} = h_0 (T_\infty - T_1) + Q_{\max}.\phi(t), \qquad x = 0 \tag{2}$$

$$\begin{cases} k_1 \dfrac{\partial T_1}{\partial x} = k_2 \dfrac{\partial T_2}{\partial x}, \\ T_1 = T_2 \end{cases} \qquad x = x_1 \tag{3}$$

$$\begin{cases} k_2 \dfrac{\partial T_2}{\partial x} = k_3 \dfrac{\partial T_3}{\partial x}, \\ T_2 = T_3 \end{cases} \qquad x = x_2 \tag{4}$$

$$k_3 \frac{\partial T_3}{\partial x} = h_L (T_\infty - T_3), \qquad x = L \tag{5}$$

$$T_i(x,0) = T_{ini} \qquad 0 \le x \le x_i, \quad t = 0 \tag{6}$$

The system is characterized in terms of a nodal network and the system of equations was approximated to form a finite difference equation by the method of Cranck-Nicolson (Hoffman, 1992). The following shows the finite difference equations derived directly from the original system of equations for the nodal points inside the layers, in the layers interfaces and the boundary regions:

$$T_{i+1}^{n+1} - 2\left(\frac{1}{Fo} + 1\right) T_i^{n+1} + T_{i-1}^{n+1} = -T_{i+1}^{n} + 2\left(1 - \frac{1}{Fo}\right) T_i^{n} - T_{i-1}^{n} \tag{7}$$

In $x = 0$, $$-T_3^{n+1} + 4T_2^{n+1} + \left(-3 - \frac{h_1 \Delta x_2}{k_1}\right) T_1^{n+1} = -\frac{h_1 \Delta x_2}{k_1}\left(\frac{Q(t)}{h_1} + T_\infty\right) \quad (8)$$

In $x = L_1$, $$T_{N_1-2}^{n+1} - 4T_{N_1-1}^{n+1} + \left[3 - 3\left(\frac{-k_1 \Delta x_2}{k_2 \Delta x_1}\right)\right] T_{N_1}^{n+1} + 4\left(\frac{-k_1 \Delta x_2}{k_2 \Delta x_1}\right) T_{N_1-1}^{n} - 2\left(\frac{-k_1 \Delta x_2}{k_2 \Delta x_1}\right) T_{N_1-2}^{n} = 0 \quad (9)$$

In $x = L_2$, $$T_{M+2}^{n+1} - 4T_{M+1}^{n+1} + \left[3 - 3\left(\frac{-k_2 \Delta x_2}{k_3 \Delta x_1}\right)\right] T_{M}^{n+1} + 4\left(\frac{-k_2 \Delta x_2}{k_3 \Delta x_1}\right) T_{M-1}^{n} - \left(\frac{-k_2 \Delta x_2}{k_3 \Delta x_1}\right) T_{M-2}^{n} = 0 \quad (10)$$

and in $x = L$, $$\left(3 + \frac{h_3 \Delta x_3}{k_3}\right) T_H^{n+1} - 4T_{H-1}^{n+1} + T_{H-2}^{n+1} = \frac{h_3 \Delta x_3}{k_3} T_\infty \quad (11)$$

Validation of the model was made to demonstrate the applicability of this method, where an experiment was simulated using the flash system multilayer geometry of a cylinder composed of three layers constituted as Pure Aluminum, a Sample and Pure Aluminum. The specimen was subjected to a short laser pulse on one side and the values of the temporal evolution of the theoretical temperature in the center of the face opposite the thermal disturbance is numerically calculated by solving the system of algebraic equations obtained from the finite difference method. Figure (2) shows the temporal evolution of temperature on both sides of the sample.

3. RESULTS AND DISCUSSION

The thermal diffusivity of food products is generally estimated from the knowledge of thermal conductivity, specific heat and density. The thermal diffusivity and thermal conductivity in the literature are estimated by the method of Dickerson (1965) and the method of linear probe heating (Vissotto et al., 1997, Simões et al., 2000, Queiroz, 2001). These experiments allow obtaining expressions from polynomial regressions leading empirical correlations as a function of humidity or temperature, or a function of both temperature and moisture content. The correlation for density, specific heat and thermal conductivity to assess the thermal diffusivity is estimated from its definition, i.e. the ratio of the thermal conductivity and heat capacity of the product.

The density of dairy products was determined by pycnometer for the temperature range of 20 - 50°C. For the commercial brands of milk the average value was 1.028 g/cm^3. Table (1) presents the average values of thermal properties for the samples milk for the temperature range of 20 - 60°C using Laser Micro Flash LFA 457.

Table 1. Thermophysical properties of milk

Thermal Properties	**Temperatures (ºC)**				
	20	30	40	50	60
Specific Heat (J/g K)	4.650	4.689	4.789	4.779	4.753
Thermal Conductivity (W/m K)	0.340	0.360	0.368	0.400	0.415
Thermal Diffusivity (mm^2/s)	0.327	0.338	0.356	0.387	0.395
Std. Deviation (mm^2/s)	0.00440	0.0452	0.0170	0.00246	0.00343
Correlation Coefficient	0.999	0.999	0.999	0.999	0.999

The thermal conductivity, thermal diffusivity and specific heat are shown in Fig. (4), computed by Micro-flash LFA 457 using the Netzsch Proteus software. The thermal conductivity of the samples was determined by the equipment directly from the values of density, specific heat and thermal diffusivity. The variation of average thermal properties of milk with temperature is shown in figure (3) and figure (3) cooling curves of the numerical model and experimental.

The thermal diffusivity was estimated for the milk from the experimental values of specific heat and density. The thermal diffusivity ranges from 0.327 to 0.395 mm^2/s for milk. The average values of thermal conductivity of the samples went from 0.350 to 0.415W/mK for milk. According to Tavman (1999), the thermal conductivity of the milk found in the literature ranges from 0.278 to 0.491W/m K. The values available in literature for dairy products are consistent with the values calculated using the flash method.

The estimated values for thermal diffusivity are slightly higher than those estimated by linear regression.

The standard deviation and the correlation coefficient between the temperature signal (raw data) and the model used to fit the data are also presented in Table. 1. The correlation coefficient is used to determine the best mathematical model for the thermal diffusivity calculation. Generally, the best mathematical model for the tests conducted was that of 3-Layers with pulse correction, even though all the methods had a coefficient very close.

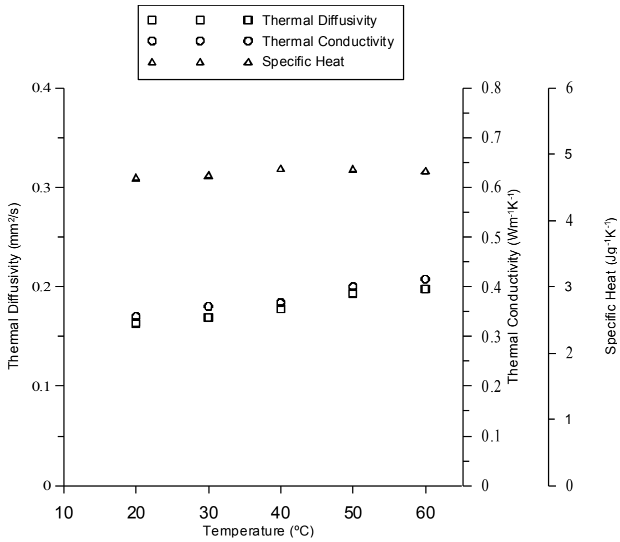

Figure 3. Diagram of Thermophysical properties of milk

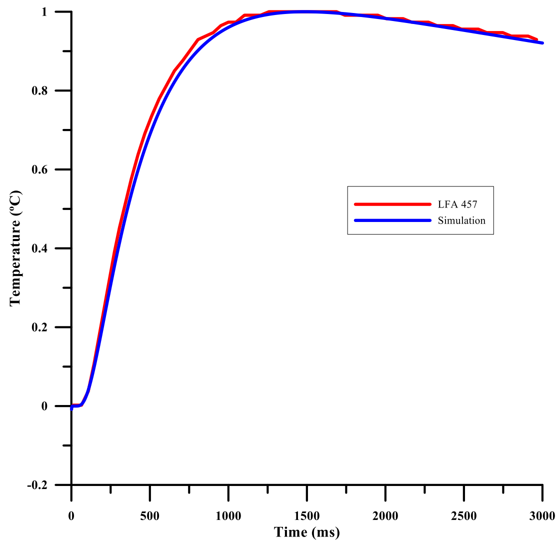

Figure 4. Diagram of numerical model and experimental

Thus, considering the experimental accuracy, the technique used and the quality of the equipment used, we believe that the results are quantitatively more accurate than those obtained using empirical relations.

4. CONCLUSION

In this study, the estimation procedure was based on a model of transient heat diffusion. Thermal properties: conductivity and diffusivity are generally determined by the literature method of linear probe, and are dependent on specific heat and density. In this work, the thermal diffusivity and conductivity were estimated using the flash method, using the value of the density determined by the pycnometric method and the specific heat values determined using the flash. Considering the dependence of thermal conductivity with moisture content, thermal conductivity values correspond to the actual data of the tested product, which are consistent with the values available in the literature. One can appreciate that the heat diffusion model in three layers is perfectly suitable to estimate the thermal diffusivity of dairy products through the Flash Method. The study allowed providing values for the thermal conductivity and thermal diffusivity of dairy products to food code calculations for design of industrial processes.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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