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Excel as an electronic method for determining thermal diffusivity from experimental data

Excel como método eletrônico para determinação da difusividade térmica a partir de dados experimentais

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Resumo

É indubitável que, com o desenvolvimento industrial, a caracterização termofísica de materiais e substâncias tornou-se uma necessidade a fim de, entre outros motivos, maximizar o desempenho de equipamentos e a eficiência das mais diversas operações unitárias. Nesse contexto, estudos relacionados à difusividade térmica, uma propriedade que está diretamente relacionada com a transferência de calor entre materiais, são cada vez mais recorrentes. Um aparato simples e eficaz para estimar a difusividade térmica de forma experimental e direta foi elaborado por Dickerson (1965), e desde então vem sendo amplamente utilizado em pesquisas relacionadas à essa temática. No entanto, considerando que experimentalmente obtém-se uma série de dados relacionados, por exemplo, às dimensões do equipamento, bem como valores de tempo e temperatura, é importante equacioná-los de forma eficiente a fim de se obter resultados que possibilitem inferir o máximo de informações acerca do objeto de estudo. Assim sendo, com este trabalho, propõe-se a utilização de planilhas eletrônicas, desenvolvidas a partir do software Microsoft Excel, para tratamento de dados experimentais obtidos pelo aparato de Dickerson. A funcionalidade das planilhas foi verificada por meio da resolução de cálculos, na forma manual e eletrônica, demonstrando eficiência e maior precisão e agilidade do método computacional, além do potencial para ser utilizado na caracterização termofísica de diversos materiais ou substâncias.
Palavras-chave: Aparato de Dickerson. Caracterização termofísica. Difusividade térmica. Excel.

Abstract

It is undoubted that, with industrial development, the thermophysical characterization of materials and substances, among other reasons, maximizes the performance of equipment and the efficiency of the most diverse unit operations. In these studies, related to thermal diffusivity, a property that is

directly related to the heat transfer between materials, are increasingly recurrent. A simple and effective apparatus for estimating thermal diffusivity in an experimental and direct way was developed by Dickerson (1965), and since then it has been widely used in research related to this topic. However, considering that experimentally, a series of data is obtained related, for example, to the dimensions of the equipment, as well as the time values, and efficiently in order to obtain results that make it possible to infer as much information about the object of study as possible. Therefore, with this proposed work, the use of electronic spreadsheets, calculated for Excel data processing, from the experimental Microsoft software obtained by the apparatus. The functionality of the physical spreadsheets was verified through the electronic calculation resolution, in the manual form and in the demonstration of efficiency and agility of the computational method, in addition to the characterization of the potential for several materials or substances.
Keywords: Dickerson's apparatus. Thermophysical. Characterization. Thermal diffusivity. Excel.

1. Introduction

Large-scale industrial development is perpetuated as one of the main characteristics of contemporaneity. In industries in general, most of the processing of various raw materials involves thermal STEPS of heating and cooling, as well as pumping fluids, to obtain products of interest. In this sense, knowledge of thermophysical properties of substances and materials, such as thermal diffusivity, thermal conductivity and specific heat, and how these properties behave during the process, as a function of temperature, are extremely important for modeling and guaranteeing efficiency and process safety, in addition to reducing energy costs or equipment sizing (Marcotte et al., 2008).

In this context, although very useful, specific information related to the thermal diffusivity of materials and substances is still scarce in the literature. Aiming to circumvent this obstacle and improve the food production sector, studies related to the identification and thermophysical characterization of food are emerging, among which we mention the research developed by Mohamed (2010) and Bento, Baesso and Silva (2022), which had the objective was to develop methods to determine the thermal diffusivity of solid foods and fish scales, respectively. In these works, the importance of this property was emphasized to avoid equipment failures, as well as to guarantee more scientific information about food, industrial processes and even to monitor the environmental integrity of certain ecosystems.

According to Incropera and Witt (2003), thermal diffusivity is a physical property described as a relationship between the ability of a fluid or material to conduct and store energy and specific mass of the material under study. A high value of thermal diffusivity implies rapid reactions to thermal changes in the environment, while small values provoke slower responses, taking time to reach a new equilibrium state (Incropera and Witt, 2003).

In addition to being widely studied in the food field, knowledge of thermal diffusivity is also important for other sectors such as metallurgy and nanotechnology. Hay et al. (2005) and Raj Sha et al. (2021) sought to determine the value of this property in samples of iron, Epoxy resin and silicon nanoparticles, respectively.

In addition to the equational mechanism, the calculation of the thermal diffusivity value can be performed directly by experimentation, which requires less elaborate instrumentation and time, since it is not necessary to know other thermophysical properties such as specific heat and thermal conductivity, for example. For this purpose, over the years, some researchers have developed techniques to estimate values of this thermophysical property (Dickerson, 1965; EL-Brolossy; Saber, 2013; Soltaninejad et al., 2013). Among these, the development of a simple and practical equipment, capable of determining the thermal diffusivity of different fluids and materials, proposed by Dickerson (1965) stands out.

This method, which was later used by authors such as Tellis-Romero et al. (1998) and Andrade Souza et al. (2010), is based on the insertion of samples into an aluminum cylinder in a water bath, linearly increasing the temperature over time with agitation and constant heating rate. During the experiments, data on time, temperature, as well as dimensions of the cell used must be collected. To assist in this practical step, citing Vieira et al. (2019) and Ortiz (2020), the use of Microsoft Excel is an advantageous alternative, which makes it possible, through electronic spreadsheets, to organize experimental data, perform calculations quickly and obtain reliable results.

In this bias, the present work aimed to build Excel spreadsheets for the experimental determination of the thermal diffusivity of materials and substances by the Dickerson method (1965), in order to speed up mathematical calculations, improve the reliability of the results obtained and observe the behavior of this property under different temperature conditions.

2. Material and methods

The spreadsheets were prepared using Microsoft Excel software and based on the methodology proposed by Dickerson (1965), for experimental determination of thermal diffusivity. Due to being accessible and practical, this technique has been used by several researchers, in order to estimate the value of this property in substances and materials. The innovative character of the method proposed by Dickerson stands out for the construction of an apparatus capable of quantifying the value of the thermal diffusion coefficient without requiring the knowledge of other thermophysical properties such as specific heat and thermal conductivity, which would be necessary if we opted for the method equational.

This apparatus is composed of a metallic cylinder in which the sample to be analyzed is placed. The experiment should be carried out in a water bath with constant agitation. As the cylindrical body presents high conductivity, the ends have to be insulated with plastic stoppers, and thermometers are attached to monitor the temperatures, one inserted on the external surface and the other internally, in the center of the cylindrical section. Thus, during the procedure, time and temperature data are collected until a constant rate of temperature increase is reached in both thermometers. After collecting these data, the thermal diffusivity can be calculated by equation 1, proposed by Dickerson (1965):

$$\boldsymbol{\alpha} = \frac{H \cdot R^2}{4 \cdot (T_{ext} - T_{int})} \tag{1}$$

Where: α is the thermal diffusivity of the sample (m²/s), H is the constant heating rate for the bath (°C/s), obtained by the slope of the linear regression line in a graph of temperature versus time, constructed with experimental data, R is the radius of the cylindrical cell and (Text – Tint) is the difference between the outside temperature and the temperature of the inner central region of the cell (°C).

The spreadsheets were created with the objective of helping the data processing stage, being useful to speed up mathematical calculations, improve the reliability of the results obtained and observe the behavior of the property studied under different temperature conditions. To help its performance, some instructions to the user were described in the spreadsheets themselves, related to inserting the data in the appropriate cells, so that Microsoft Excel can properly return the calculated values. The first worksheet, called "EXPERIMENTAL DATA", is intended to fill in the data obtained experimentally. The layout of this page is represented in Figure 1.

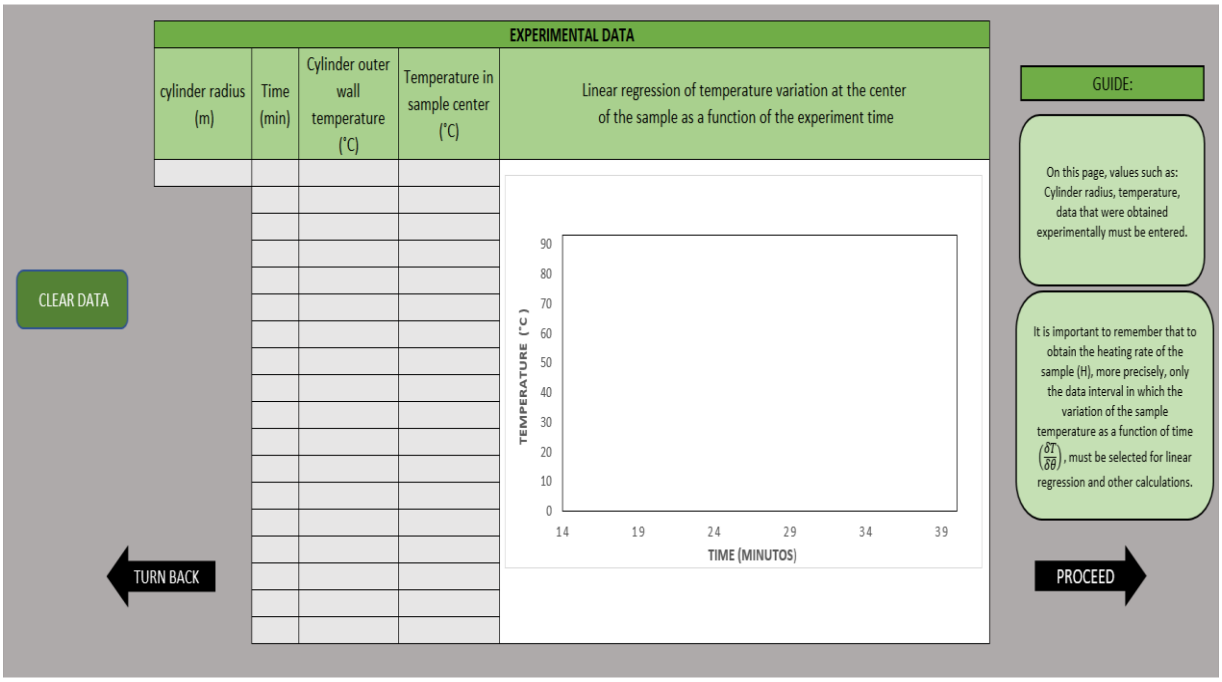


Figure 1 – Layout of the page for filling in the experimental data.

As can be seen in Figure 1, this first worksheet contains the cells for filling in the variable and fixed experimental values, which are time values in (minutes), internal and external temperature in (˚C) and cylinder diameter in (m). Together, a model for linear regression analysis of the experimental data is coupled. After filling the cells, this model will relate the temperature variation in the center of the cylindrical capsule with time. In this case, the adjustment is necessary to obtain the slope (a) of the first-degree function (y= ax+b), which represents the heating rate of the sample, denoted in (˚C/min). In this step, it is important to provide or select a data interval in which the temperature versus time relationship is as linear as possible, in order to obtain a satisfactory correlation coefficient (R^2), being equal to or very close to 1, and an equation that describes in an acceptable way the dependence between the temperature and time gradients. After compiling the data and obtaining the adjustment and heating rate of the sample, which will now be denoted by "H", using the "DATA TREATMENT" worksheet, which has its layout shown in Figure 2, it is possible to perform the calculations to determine the thermal diffusivity at each temperature value listed and obtain some statistical measurements of the values found, such as mean, variance, standard deviation and coefficient of variation.

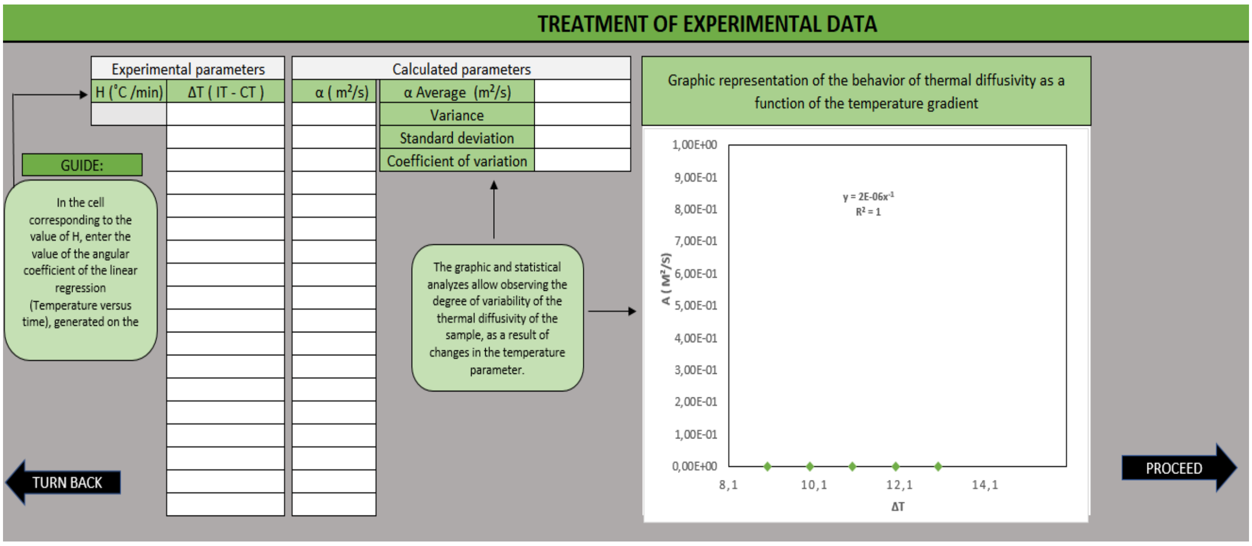
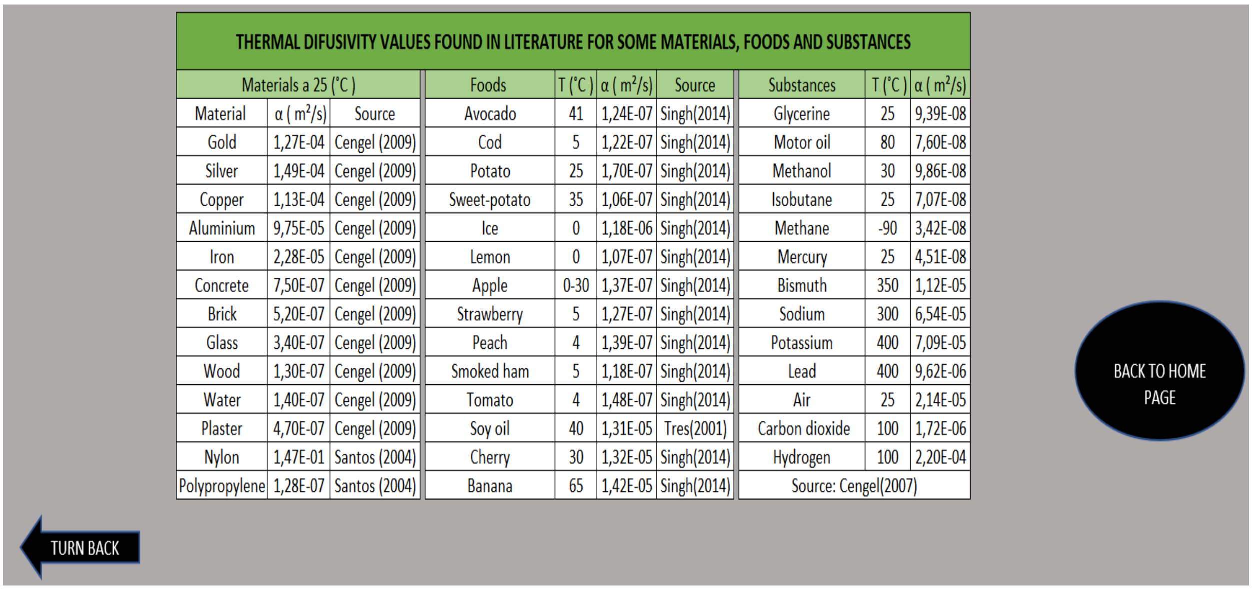


Figure 2 – Layout of the page "Treatment of experimental data".

Thus, this step must be started by calculating the temperature gradients (ΔT), observed between the center of the cylindrical capsule and its outer wall, throughout the experiment. These calculations are performed automatically, after entering the data in worksheet 1, so that, also knowing the radius of the cylinder and the heating rate (H) previously determined, the thermal diffusivity can be calculated through equation (1). To complete the data processing, the Excel (2013) functions "AVERAGE", "VAR.P", "STDEV.P" already inserted in the worksheet, allow you to automatically determine the mean value, variance, standard deviation and coefficient of variation of the values obtained for the thermal diffusion coefficient, in the selected time and temperature interval. This statistical analysis is important for estimating a value for the thermal diffusivity in the desired temperature range and to analyze how much the behavior of this property is influenced by changes in this parameter.

As shown, the spreadsheets were designed to receive experimental data according to Dickerson's (1965) method, in which the light gray cells should receive the data obtained during the experiment and the blank cells provide values for the calculated properties. In addition to the structure for automatically performing the calculations involved in the determination of thermal diffusivity, a spreadsheet containing values of this property found in the literature for some foods, materials and substances was attached, which may be useful for validating the calculations and the experiment performed. The layout of this page is shown in Figure 3.



THERMAL DIFUSIVITY VALUES FOUND IN LITERATURE FOR SOME MATERIALS, FOODS AND SUBSTANCES

Materials a 25 (°C)			Foods	T (°C)	α (m^2/s)	Source	Substances	T (°C)	α (m^2/s)
Material	α (m^2/s)	Source	Avocado	41	1,24E-07	Singh(2014)	Glycerine	25	9,39E-08
Gold	1,27E-04	Cengel (2009)	Cod	5	1,22E-07	Singh(2014)	Motor oil	80	7,60E-08
Silver	1,49E-04	Cengel (2009)	Potato	25	1,70E-07	Singh(2014)	Methanol	30	9,86E-08
Copper	1,13E-04	Cengel (2009)	Sweet-potato	35	1,06E-07	Singh(2014)	Isobutane	25	7,07E-08
Aluminium	9,75E-05	Cengel (2009)	Ice	0	1,18E-06	Singh(2014)	Methane	-90	3,42E-08
Iron	2,28E-05	Cengel (2009)	Lemon	0	1,07E-07	Singh(2014)	Mercury	25	4,51E-08
Concrete	7,50E-07	Cengel (2009)	Apple	0-30	1,37E-07	Singh(2014)	Bismuth	350	1,12E-05
Brick	5,20E-07	Cengel (2009)	Strawberry	5	1,27E-07	Singh(2014)	Sodium	300	6,54E-05
Glass	3,40E-07	Cengel (2009)	Peach	4	1,39E-07	Singh(2014)	Potassium	400	7,09E-05
Wood	1,30E-07	Cengel (2009)	Smoked ham	5	1,18E-07	Singh(2014)	Lead	400	9,62E-06
Water	1,40E-07	Cengel (2009)	Tomato	4	1,48E-07	Singh(2014)	Air	25	2,14E-05
Plaster	4,70E-07	Cengel (2009)	Soy oil	40	1,31E-05	Tres(2001)	Carbon dioxide	100	1,72E-06
Nylon	1,47E-01	Santos (2004)	Cherry	30	1,32E-05	Singh(2014)	Hydrogen	100	2,20E-04
Polypropylene	1,28E-07	Santos (2004)	Banana	65	1,42E-05	Singh(2014)	Source: Cengel(2007)		

Figure 3 – Layout of the page "Thermal diffusivity values found in literature for some foods, materials and substances".

3. Results and discussion

Considering the industrial development on a large scale, as one of the main characteristics of contemporaneity, the knowledge of thermophysical properties such as thermal diffusivity, specific heat and thermal conductivity of materials or substances, has become a necessity to increase the efficiency of the most diverse processes. In this sense, research by Marcotte, Taherian and Karimi (2008), reports the great importance of the study of thermal diffusivity for the modeling, safety and optimization of industrial unit operations, with emphasis on steps involving heat transfer, such as drying, pasteurization and cooking, characteristics of the food production sector. Based on this principle, this work, through the creation of electronic spreadsheets, aims to speed up and increase the precision of the treatment of experimental data obtained with the determination of the thermal diffusivity of materials or substances, using the methodology created by Dickerson (1965), which stands out in relation to the equational method and other experimental techniques, as it requires less study time and instrumentation expenses.

Thus, to demonstrate the functionality of the created spreadsheets, an application example was used, with experimental data from a work developed by Paiva and Razuk (2007), which aimed to estimate the thermal diffusivity of tomato extract with different solids contents. In this research, for the construction of the apparatus and execution of the experiment, following the descriptions of Dickerson (1965), the following were used: A stove, a thermostat, an aluminum cylinder with a diameter of 0.03 meters (m), 0.1 m height and 0.0015 m thick, 2 thermocouples properly calibrated and samples of tomato extract of different brands and soluble solids contents. The property under study was determined with the aid of a cylindrical container capped with rigid PVC, containing 2 fixed thermocouples, one in the center and the other on its external wall. At the moment the thermostat was turned on, at an interval of 2 minutes, the temperatures in these 2 regions were recorded, until the sample in the center of the cylinder reached approximately 90 ˚C (Paiva and Razuk, 2007). The values found are listed in table 1.

Table 1 – Experimental data obtained by Paiva and Razuk (2007), with the determination of the thermal diffusivity of tomato extract with different solids.

TIME (minutes)	CYLINDER INTERNAL WATER TEMPERATURE (˚C)	TEMPERATURE AT THE CENTER OF THE SAMPLE (˚C)
6	26.1	23.6
8	28.5	24.7
10	31.6	26.1
12	34.8	28.1
14	38.7	30.6
16	43.1	33.5
18	47.6	37.0
20	52.2	40.8
22	57.4	45.0
24	62.7	49.6
26	68.2	54.5
28	73.8	59.7
30	79.9	64.8
32	85.6	70.2
34	91.6	75.7
36	97.4	81.7
38	102.5	87.5
40	107.9	92.6

Before starting the calculations, it is important to remember that although all the values obtained are recorded, as recommended by Dickerson, only the time and temperature values at which the heating of the sample as a function of time $\left(\frac{\delta T}{\delta \theta}\right)$, was linear, which in the case of the work by Paiva and Razuk (2007), used as an example, began to be observed in a time equal to 14 minutes.

3.1 Handling data manually:

The first step in data processing is the determination of the heating rate (H) of the sample as a function of time. Considering constant at all points, the heating speed of the bath in which the cylinder is inserted, this value corresponds to the angular coefficient of the 1˚ degree equation (Y=ax+b), representative of the temperature variation of the extract sample of tomato throughout the experiment. Therefore, the heating rate (H) in (˚C/min) can be estimated by equation 2, taking the ratio between 2 ordered pairs of an interval with linear behavior, 1 of the X axis (time in minutes) and the other from the Y axis (sample temperature).

$$H=\frac{\Delta y}{\Delta x} \qquad (2)$$

where: Δy is the temperature gradient and Δx is the time gradient. Thus, choosing the ordered pair (X, Y): **Δx=** (28 - 30) min **Δy=** (64.8 – 59.7) ˚C, one has to:

$$\frac{\Delta y}{\Delta x}=\frac{(y_b-y_a)}{(x_b-x_a)} \qquad \frac{\Delta y}{\Delta x}=\frac{(64.8-59.7)^{\circ}C}{(30-28)\,min} \qquad \frac{\Delta y}{\Delta x} = 2.55\ (^{\circ}C/min)$$

It follows that the heating rate (H) of the sample under study is approximately 2.55 ˚C/min, or 0.0425 ˚C/s. However, it is important to note that the manual calculation of the heating rate is subject to generating an inaccurate result, as the information is removed from only two ordered pairs from the entire data set. On the other hand, if performed electronically, all time and temperature values of the experiment are considered in the calculation and a more real description of the heating rate of the sample under study can be provided. After determining the heating rate, the temperature gradients found between the center of the cylinder containing the sample and its outer wall must be calculated at each time interval, using equation (3). The calculations performed and the results obtained are listed in table 2.

$$\Delta T = (EXTERNAL\ WALL\ TEMPERATURE - TEMPERATURE\ IN\ THE\ CENTER\ OF\ THE\ SAMPLE). \qquad (3)$$

Table 2 - Calculations performed and results obtained with the determination of the temperature gradient existing between the outer wall of the cylinder and the center of the sample.

Time (min)	**Δ*T = (Inner T - Center T)* *(˚C)***	**Δ*T* *(˚C)***
14	(38.7 – 30.6)	8.1
16	(43.1 – 33.5)	9.6
18	(47.6 – 37.0)	10.6
20	(52.2 – 40.8)	11.4
22	(57.4 – 45.0)	12.4
24	(62.7 – 49.6)	13.1
26	(68.2 – 54.5)	13.7
28	(73.8 – 59.7)	14.1
30	(79.9 – 64.8)	15.1
32	(85.6 – 70.2)	15.4
34	(91.6 – 75.7)	15.9
36	(97.4 – 81.7)	15.7
38	(102.5 – 87.5)	15.0
40	(107.9 - 92.6)	15.3

Now, the next step is to calculate the thermal diffusivity at each time interval. For this, equation (1) will be used. Substituting the same calculated values for sample heating rate, cylinder radius and temperature difference of the inner wall and central region of the cylinder at each time interval, we have the following results as shown in table 3:

Table 3 – Thermal diffusivity calculated at each time and temperature interval.

Time (min)	*α (m²/s)*
14	$2.95x10^{-7}$
16	$2.49x10^{-7}$
18	$2.26x10^{-7}$
20	$2.1x10^{-7}$
22	$1.93x10^{-7}$
24	$1.82x10^{-7}$
26	$1.74x10^{-7}$
28	$1.7x10^{-7}$
30	$1.58x10^{-7}$
32	$1.55x10^{-7}$
34	$1.50x10^{-7}$
36	$1.52x10^{-7}$
38	$1.59x10^{-7}$
40	$1.56x10^{-7}$

By obtaining the thermal diffusivity as a function of temperature and experiment time, it is possible to estimate, among the results obtained, the mean value, the variance, the standard deviation and the coefficient of variation of this property in the selected interval. The average coefficient of thermal diffusion for a temperature range considered can be obtained by means of a simple arithmetic average, calculated by adding all the results of the data set referring to thermal diffusivity and dividing by the number of elements of this set, as represented by the equation (4) (Farber and Larson, 2010):

$$\bar{x} = \frac{\sum x_i}{n} \quad (4)$$

Where: $\bar{x}$ is the simple arithmetic mean, $\sum xi$ is the sum of data and n is the total number of the data (where n=14).

The sample variance, in turn, according to Farber and Larson (2010), takes into account the extreme and intermediate values of thermal diffusivity found, better expressing the results obtained, with the calculation of the arithmetic mean of the squares of the deviations, as described by the equation (5). Its unit of measurement will always be the square of the unit of observation (m^4/s^2).

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} \quad (5)$$

Where: S^2 is the variance, *xi* is a random value from the data set, $\bar{x}$ is the simple arithmetic mean, and n is the number of data (where n=14).

By calculating the value of the sample variance, it is then possible to determine the standard deviation of the data set. This statistical measure demonstrates the degree of variability of the data in relation to its mean value, which can be mathematically determined by taking the square root of the variance, as described in equation 6 (Farber and Larson, 2010).

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \qquad (6)$$

Where: σ = standard deviation, *xi* is each value in the data set, $\bar{x}$ is the simple arithmetic mean, and n is the number of data (where n=14).

The coefficient of variation (C.V), according to Storck et al. (2011), is a measure of dispersion used to describe the variation of the data obtained in relation to the mean and then estimate the precision of an experiment. The coefficient of variation of thermal diffusivity, as shown in equation 7, represents the standard deviation expressed as a percentage of the mean, and is of great importance in comparing the results of different studies involving the same research.

$$C.V. = \left(\frac{\sigma}{\bar{x}}\right) \text{ x } 100\% \qquad (7)$$

Where: C.V. is coefficient of variation, σ is the standard deviation and $\bar{x}$ is the simple arithmetic mean.

Applying the equations described, the average value of thermal diffusivity found was $1.88\text{x}10^{-7}$ m²/s, the variance $1.72\text{x}10^{-15}$, the standard deviation $4.15\text{x}10^{-8}$, and the coefficient of variation equal to 22.1%.

Processing of data electronically using spreadsheets: First, as shown in Figure 4, the experimental data of temperature of the sample and of the inner wall of the cylinder were entered on the “Experimental data” page, in each time interval lasting 2 minutes, throughout the experiment.

Time (min)	Cylinder outer wall temperature (˚C)	Temperature in sample center (˚C)
6	26.1	23.6
8	28.5	24.7
10	31.6	26.1
12	34.8	28.1
14	38.7	30.6
16	43.1	33.5
18	47.6	37.0
20	52.2	40.8
22	57.4	45.0
24	62.7	49.6
26	68.2	54.5
28	73.8	59.7
30	79.9	64.8
32	85.6	70.2
34	91.6	75.7
36	97.4	81.7
38	102.5	87.5
40	107.9	92.6

Figure 4 – Layout of part of the “Experimental data” page.

After filling in the table, selecting the interval which describes a uniform variation of the temperature of the sample as a function of time (after a time of 14 minutes), it is determined by means of a simple linear regression model, the constant heating rate of the sample (H) in ˚C /min which corresponds to the angular coefficient (A) of the 1˚-degree equation (y= ax+b) generated, being able to visualize the rise in temperature of the same, throughout the experiment, as shown in figure 5.

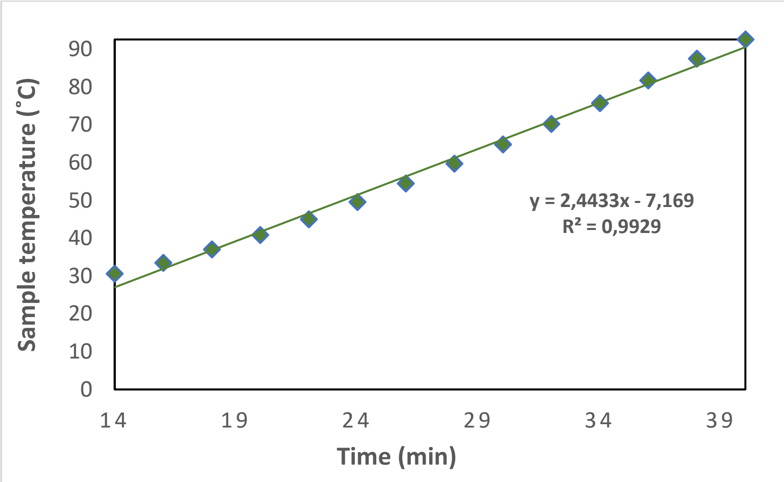


Figure 5: Temperature variation of the tomato extract sample as a function of time.

Thus, the value determined for the heating rate of the sample in ˚C/min, converted to the unit ˚C/s and the measurement of the radius of the cylinder used in the experiment, are listed in table 4:

Table 4: Values for sample heating rate and cylinder radius.

Cylinder Radius (m)	*Heating rate (˚C/s)*
0.015	0.04067

Using the electronic method to calculate the temperature gradients observed between the central region of the cylinder containing the sample and its inner wall, and from them and the other data already found, it is possible to determine the thermal diffusivity at each point. To perform these calculations automatically, equations (2) and (1) were used, respectively, which were entered in the spreadsheet. The values obtained are shown in Figure (6):

ΔT (IT - CT)	α (m²/s)
2.5	9.15×10^{-7}
3.8	6.02×10^{-7}
5.5	4.16×10^{-7}
6.7	3.41x10-7
8.1	2.82×10^{-7}
9.6	2.38x10-7
10.6	2.16×10^{-7}
11.4	2.01×10^{-7}
12.4	1.84×10^{-7}
13.1	1.75×10^{-7}
13.7	1.67×10^{-7}
14.1	1.62×10^{-7}
15.1	1.51×10^{-7}
15.4	1.49×10^{-7}
15.9	1.44×10^{-7}
15.7	1.46×10^{-7}
15.0	1.53×10^{-7}
15.3	1.50×10^{-7}

Figure 6: Layout of part of the page "Treatment of experimental data", demonstrating the space destined to calculate the temperature gradient and thermal diffusivity at each point.

The thermal diffusivity values obtained ranged from $2.82x10^{-7}$ to $1.5x10^{-7}$ m²/s. The difference between these values can be explained by the heating of the sample over time, since according to Incropera and Witt (2003), thermal diffusivity is a thermophysical property influenced by variables such as temperature, water content, composition and porosity. To finish the data treatment, as shown in figure 7, the statistical measures mean, variance, standard deviation and coefficient of variation are calculated for the results obtained. As in this case it will be done using Microsoft Excel, the AVERAGE, VAR and DESVPAD.P functions, which are available in this software, can be used to calculate the mean and variance and standard deviation. The coefficient of variation, in turn, can be obtained by applying equation (6).

α Average (m²/s)	$1.80x10^{-7}$
Variance	$1.58x10^{-15}$
Standard deviation	$3.97x10^{-8}$
Coefficient of variation	22.1%

Figure 7: Layout of part of the page "Treatment of experimental data", demonstrating the space destined to the calculations of the average value of thermal diffusivity and variability of the obtained data.

As shown, in the temperature range used in the experiment (30.8˚C to 92.6˚C), the tomato extract sample showed an average thermal diffusivity of $1.8x10^{-7}$ m²/s. The variance of the 14 data obtained in relation to this mean value was $1.58x10^{-15}$ m^4/s^2, with a standard deviation of $3.97x10^{-8}$ m²/s and a coefficient of variation of 22.1%, which according to Storck et al. (2011), in statistical terms it is considered a high degree of variation coefficient. However, as the diffusivity is influenced by the conditions of the environment, and there were changes in the temperature parameter over time, this variation can be considered normal and acceptable.

After carrying out all the necessary calculations through the computational version, it was possible to perceive that the results obtained were slightly different from those found by the manual resolution. In this sense, it was found that this occurred due to a discrepancy between the values found for the heating rate of the sample (H). The calculation of this property, when performed manually, is subject to generating an imprecise result, since the information is extracted from only one point chosen randomly from the data set. On the other hand, with the use of the software, this value becomes more precise and secure, given that the entire range of interest is analyzed. Thus, it is concluded that electronic spreadsheets created in Microsoft Excel are advantageous for use in the treatment of data obtained with the experimental determination of thermal diffusivity by the Dickerson method (1965), mainly due to the agility, precision and better visualization of the results achieved.

4. Conclusion

It was verified, with the results obtained in this work, the importance of the knowledge of thermophysical properties for the characterization of foods, substances and materials as well as its applicability in the industrial sector and in the most diverse areas. Therefore, considering the low availability of reference data for thermal diffusivity in the literature and the main existing difficulties regarding the indirect determination of this property, electronic spreadsheets were created based on the direct determination methodology developed by Dickerson (1965), in order to alleviate the challenges and promote studies related to this theme. The functionality of the electronic method developed in Microsoft Excel software, and intended for the treatment of experimental data, was verified by performing the resolution of the calculations manually and electronically, and comparing the results obtained in the two methods. In this sense, it was possible to conclude that the developed spreadsheets showed efficiency in the treatment of experimental data obtained with the determination of thermal diffusivity by the method of Dickerson (1965), obtaining results in a more agile and precise way, with the potential to be used in the thermophysical characterization of various items.

5. Supplementary Material

The worksheets created to receive experimental data obtained with the determination of thermal diffusivity by the Dickerson method (1965), were the basis for the elaboration of this article and are attached as a complementary material referring to the same, in order to facilitate the understanding of the readers. And demonstrate the applicability of the electronic method developed. In this way, the authors allow the free content of these contents, to be made available on the jCEC website.

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