Data processing software for calculating the thermal conductivity of building materials by application of the box method

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Abstract An in this article, we present software for data acquisition and calculation of thermal conductivity and thermal diffusivity of building materials that we have developed. The software makes it possible to visualize the evolution of the temperatures of up to four thermocouples through a data acquisition system. The supported acquisition systems are: USB TC-08, AquiData, Keysight 3970A/3972A. Thermal conductivity is determined by the method of boxes. Characterization can be carried out from an Excel file or from the acquisition system.

1. Introduction

With the climate change observed by global warming, the consequences of which are harmful to the environment, the construction of dwellings must meet specific energy requirements in order to reduce their energy consumption, which represents a significant part of the energy bill in Africa [1] [5]. To achieve this, new construction materials with better energy efficiency must be developed. A thermo-physical characterization is necessary [2] to assess the quality of the material to meet the energy requirements. There are thermo-physical characterization methods such as the box method, the hot plate method, the hot wire method, the hot plane method, etc. which determine the thermal properties of materials. Each method is more or less suitable for a certain type of material. The box method is one of the best suited to characterize building materials. Because of its ease of implementation and its satisfactory results, it is one of the most widely used methods. However, its use, like the others, requires the use of data acquisition devices. These are most often supplied with a computer program whose main role is to display on a computer screen the evolution of the physical quantities being acquired and to record the data received in the form of Excel file. Thus, to obtain the desired thermal properties, these data must be exploited. Which is extra work and a waste of time. It was with the aim of sparing the user this additional task that it was decided to develop data processing software applied to the box method.

This tool will display in real time the physical quantities being acquired, in particular the temperature, but also will calculate the thermal conductivity when the required conditions are met. In this work, it will be a question of first presenting the box method, then designing the processing software and finally presenting the simulation results.

2. Materials and Methods

2.1. Introducing the box method

It consists of placing a sample of the material to be characterized in a box in which there is a heating film. The upper face of the sample is subjected to the heat flow of the heating resistor while the lower face is exposed to a cooled environment [3] [6].
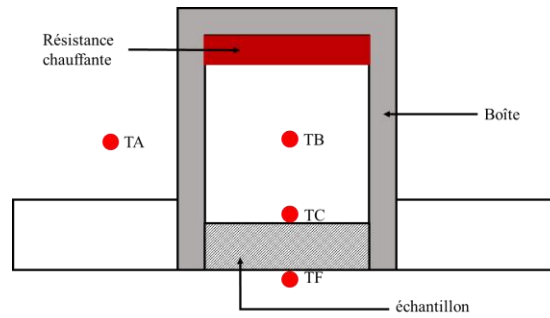
Figure 1: Experimental setup of the box method

A voltage current V_B is passed through the heating film and following temperatures are regularly sampled :

- T_A : room temperature;
- T_B : box temperature;
- T_C : hot face temperature;
- T_F : cold face temperature.

Once the steady state has been reached, i.e. when the temperature values will be constant for about half an hour, the expression for the heat flow Φ given below is used to calculate the thermal conductivity.

$$\varphi_c = \frac{\lambda}{e}(T_C - T_F)A + C_B(T_B - T_A) \quad (1)$$

With:

φ_c : heat flux emitted by Joule effect by the film;

e : sample thickness: $4\,cm \leq e \leq 7\,cm$;

A : sample area : 27 cm x 27 cm

C_B : hot box heat loss constant;

V_B : the rms voltage applied across the terminals of the heating resistor;

R_B : heating film resistance.

The thermal conductivity is then given by the following formula [4] :

$$\lambda = \frac{e}{S(T_C - T_F)}\left[\frac{V_B^2}{R_c} - C_B(T_B - T_A)\right] \quad (2)$$

with λ , the thermal conductivity of the sample.

2.2. Processing software design

The purpose of the processing software is to visualize in real time the data received through an acquisition device, to record this data in an Excel spreadsheet and to use it to determine the thermal conductivity.
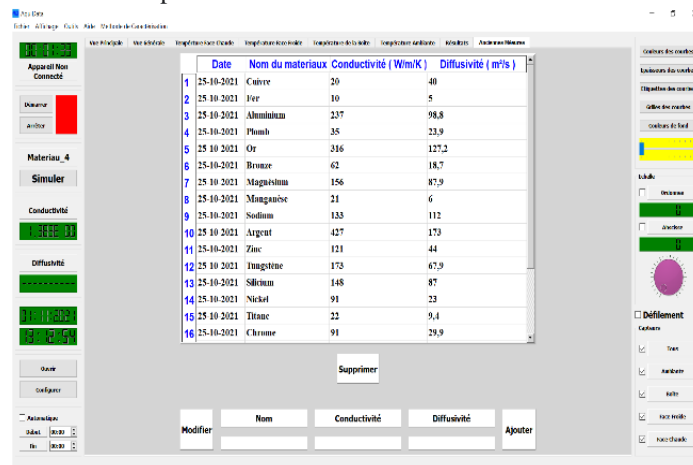
Figure 2 illustrates the software startup screen.

Figure 2: Software start page

The software offers two possibilities for calculating the thermal conductivity of the material studied. The first is to use the data previously acquired and saved in an Excel file. As for the second, it consists in determining the thermal conductivity, directly, through the reception of the data transferred by a data acquisition device. The software supports the following data loggers: USB TC-08, Keysight 3970A/3972A.

To perform the characterization from an Excel file, after selecting the characterization method from the menu « méthodes de caractérisation » you must first load the corresponding file. To do this, click on the button « Charger un fichier Excel » from the main window. A dialog box named « Charger un fichier » will open. It has a button « choisir » with which, we select the desired Excel file. An action on this button causes the opening of a file selection dialog box. Once the file is selected, press the button « Ouvrir » to validate the selection. If the file format does not correspond to the required format, you can check the box « indiquer les noms des colonnes » and fill in the name of each column in the corresponding text box. It should be noted that the data to be used must appear in the first sheet of the Excel file.

Then, it is necessary to fill in the data necessary for the characterization. We press the button « Configurer Paramètres », a dialog box named « Configuration Excel » then opens. In this dialog box, you fill in the information represented by the fields below :

- ✓ Nom du matériau : It allows you to indicate the name of the material you want to characterize ;
- ✓ Tension d'alimentation : this corresponds to the supply voltage (in V) of the heating resistor ;
- ✓ Résistance chauffante : it designates the resistance value (in Ohm) of the heating film ;
- ✓ Epaisseur de l'échantillon : it is used to enter the thickness (cm) of the sample. The thickness should not exceed 7 cm;
- ✓ Surface de l'échantillon : this box allows you to define the period (minute or second) for which you want to acquire the data;
- ✓ Coefficient de déperdition Thermique : This refers to the heat losses of the box;
- ✓ Le seuil de régime permanent : it indicates the minimal variation of the temperature, for which, one estimates that the permanent mode is established.

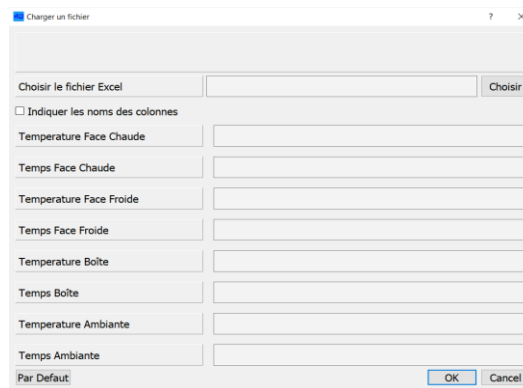Figure 3 shows the dialog box « charger un fichier ».

Figure 3: Upload file dialog box

To perform the characterization from a data-logger, after selecting the characterization method, press the button « Configuration » from the main window. A dialog box named « Configuration » is launched, in which we fill in the input parameters explained below :

In the « Fichier » section, you must fill in the following information:

- ✓ Nom du matériau : designates the name of the material to be characterized;
- ✓ Chemin d'accès : allows you to specify the folder in which you want to save the data received through the acquisition device.

At the « choix de l'appareil » label, you must choose one of the three data-loggers supported by the software, which are : « AQuiData », « USB TC-08 », « Keysight 34970A/34972A ».

For the Thermocouple label, it specifies the type of thermocouple used. Note that the type of thermocouple must be the same for all sensors.

The « Interface », label allows you to select one of the three communication interfaces used to connect the data-logger to the computer. The interfaces recognized by the software are: USB, GPIB and RS232.

In the « Numéros de voies des capteurs » section, the following information must be entered :

- ✓ Capteur Face Chaude : it indicates the number of the pin to which the thermocouple of the hot face of the sample is connected.
- ✓ Capteur Face Froide : it indicates the number of the pin to which the thermocouple of the cold face of the sample is connected.
- ✓ Capteur Boite : it indicates the number of the pin to which the thermocouple of the box is connected.
- ✓ Capteur Ambiante : it indicates the number of the pin which is connected to the ambient air thermocouple.

At the level of the « Donnée Générale » section, it is mainly the same information provided at the characterization level with Excel File. However, additional information is added, namely the « période d'échantillonnage ». It is used to indicate the time interval between two measurements.

If you do not enter the information manually, you can use the predefined values by clicking on the « Par Défaut » button in this same dialog box.

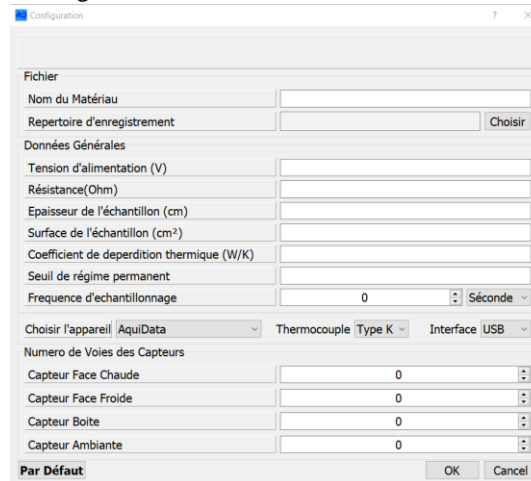Figure 4 shows the « configuration » dialog box.

Figure 4: Setup dialog box

3. Results and Discussion

We carried out an experiment with the processing software in order to verify the conformity of the results obtained with the data in the literature. To do this, we used the experimental characterization data of an extruded polystyrene sample with a density of $34\ kg.m-3$ and a standard plaster sample made with the box method. After treatment, we obtained the thermograms and the results illustrated by the following figures [7] [8].
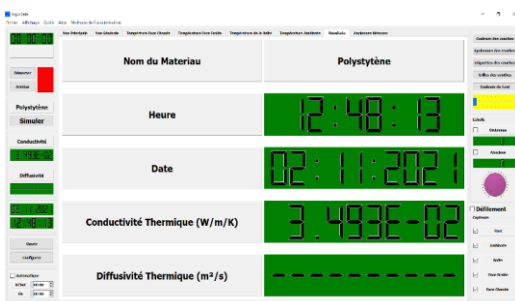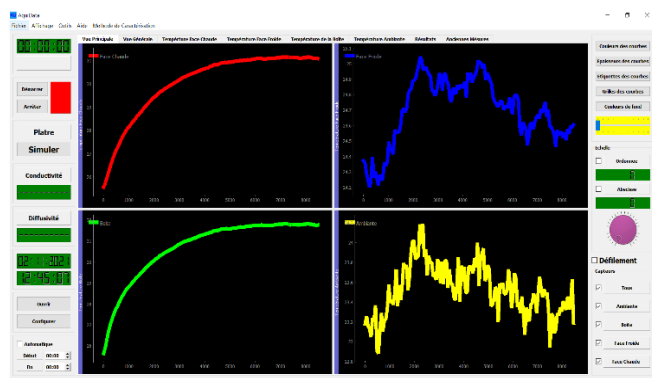

Figure 5: Polystyrene results
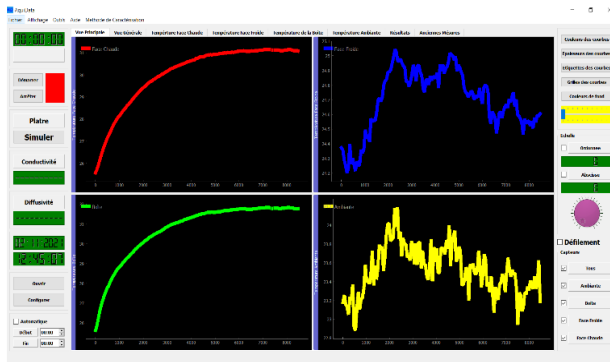

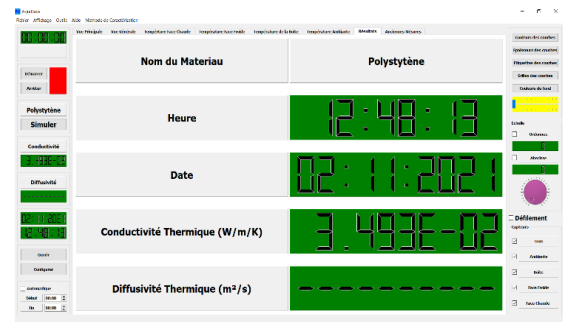*Figure 6: Polystyrene thermagrams*

Figure 7: Plaster thermograms

Figure 8: Plaster results

At the end of the treatment, we obtain a thermal conductivity of $3,493 . 10^{-2} \ W . m^{-1} . K^{-1}$ for polystyrene and $1,027 \ 10^{-1} \ W . m^{-1} . K^{-1}$ for plaster. In the literature, the conductivity of polystyrene is around $0,029 \ W . m^{-1} . K^{-1}$ to $0,037 \ W . m^{-1} . K^{-1}$ while that of plaster varies around $0,2 \ W . m^{-1} . K^{-1}$. Given the results we have obtained, we can conclude that the software gives satisfactory results.

Conclusion

The processing software that we have developed has characteristics of reliability with regard to the satisfactory results that we have obtained during the experiment. It displays in real time the temperatures acquired by the acquisition system. It offers the possibility of determining the thermal properties, either by exploiting data from an Excel file, or directly through a data acquisition system.

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