



## EVALUATION OF THERMAL PHASE SHIFT FROM THE CURVE OF TEMPERATURE OF A KAPOK-PLATTER MATERIAL IN DYNAMIC FREQUENTIAL REGIME

Dame Diao<sup>1</sup>, M.S. OuldBrahim<sup>1</sup>, Hawa Ly Diallo<sup>2</sup>, Youssou Traoré<sup>1,2</sup>, Pape Touy Traoré<sup>1</sup>, Seydou Faye<sup>1</sup>, Issa Diagne<sup>1</sup> and Grégoire Sissoko<sup>1</sup>

<sup>1</sup>Laboratory of Semiconductors and Solar Energy, Physics Department, Faculty of Science and Technology, University Cheikh Anta Diop, Dakar, Senegal

<sup>2</sup>Université de Thiès, Thiès, Sénégal  
Email: [gssissoko@yahoo.com](mailto:gssissoko@yahoo.com)

### ABSTRACT

In this article, we study the thermal phase shift of a thermal insulating material based on kapok-plaster in dynamic frequency regime. The method of determining this phase shift consists in evaluating the delay of the signal of the temperature between the front and rear faces of the material for a given excitation pulse as a function of time. The study of the influence of the pulse is also evaluated.

**Keywords:** excitation pulsation, thermal phase shift, frequency regime, thermal inertia.

### INTRODUCTION

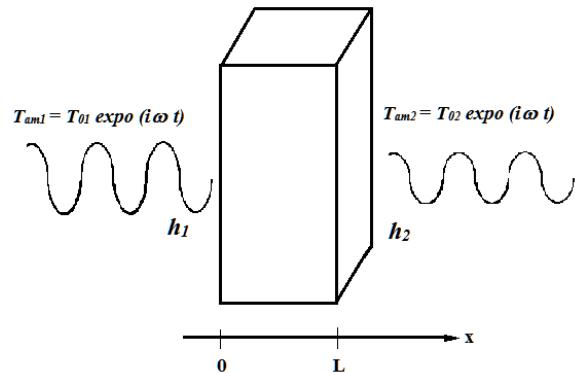
As thermal inertia [1-5], thermal phase shift plays an important role in thermal insulation [6-8], especially for countries with a hot climate. It depends on the chosen materials and their thermo physical properties [9-11]. The thermal phase shift represents the time shift during the transfer of heat from one side to the other of a wall [12]. Several studies are made on this parameter among which:

- The optimization of the thermal phase shift between the exterior and the interior of the building [13-16],
- The observation of this phase shift of the thermal wave with respect to the reference signal in order to detect defects within a material [17-19].

In this paper, we study the evolution of the temperature signal as a function of time through the material in the dynamic frequency regime with excitation pulse  $\omega$ . A method of graphical determination of the thermal phase shift is proposed, followed by the study of the influence of the pulsation on the latter.

### MODEL OF STUDY

The study model is a plaster kapok brick subjected to a thermal stress in dynamic frequency regime. At its two faces, ambient temperatures of the formed  $T_{amb} = T_0 \exp(i\omega t)$  are submitted, and the heat exchange coefficients representing convection exchanges are given by  $h_1$  and  $h_2$ . The material has a thermal diffusivity  $\alpha = 4.73 \cdot 10^{-7} \text{ m}^2 \cdot \text{s}^{-1}$  and a thermal conductivity  $\lambda = 0.1 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  and a thickness  $L = 0.05 \text{ m}$ .



**Figure-1.** Plaster kapok brick subjected to thermal stresses on both sides.

The heat transfer is studied through this device thanks to the Fourier equation with the following assumptions: the material does not possess heat source, the system is studied to a one dimension x. The ambient temperature amplitudes are given respectively by  $T_{01} = 303 \text{ K}$ ;  $T_{02} = 292 \text{ K}$ . The initial temperature of the material being  $T_i = 293 \text{ K}$

$$\frac{\partial^2 T(x,t)}{\partial x^2} - \frac{\lambda}{\alpha} \frac{\partial T(x,t)}{\partial t} = 0 \quad (1)$$

Where  $\alpha$  is the thermal diffusivity define by:

$$\alpha = \frac{\lambda}{\rho C} \quad (2)$$

With  $\rho$  and  $C$  being respectively the density and the mass calorific capacity. We seek a solution of the form  $T(x,t) = A(x) * B(t)$  by the method of the separation of variables.

The boundary and initial conditions are given by the following relations:



$$\left\{ \lambda \frac{\partial T(x, h_1, h_2, \omega, t)}{\partial x} \Big|_{x=0} = h_1 [T(0, h_1, h_2, \omega, t) - T_{a1}] \right. \quad (3)$$

$$\left\{ \lambda \frac{\partial T(x, h_1, h_2, \omega, t)}{\partial x} \Big|_{x=L} = h_2 [T_{a2} - T(L, h_1, h_2, \omega, t)] \right. \quad (4)$$

$$\left\{ T(x, h_1, h_2, \omega, 0) = T_i \right. \quad (5)$$

To get a homogeneous partial differential equation, we use the following variable change:

$$\frac{\partial^2 \tilde{T}(x, t)}{\partial x^2} - \frac{1}{\alpha} \frac{\partial \tilde{T}(x, t)}{\partial t} = 0 \quad (7)$$

$$\tilde{T} = T - T_i \quad (6)$$

The new writing of (5) gives (7):

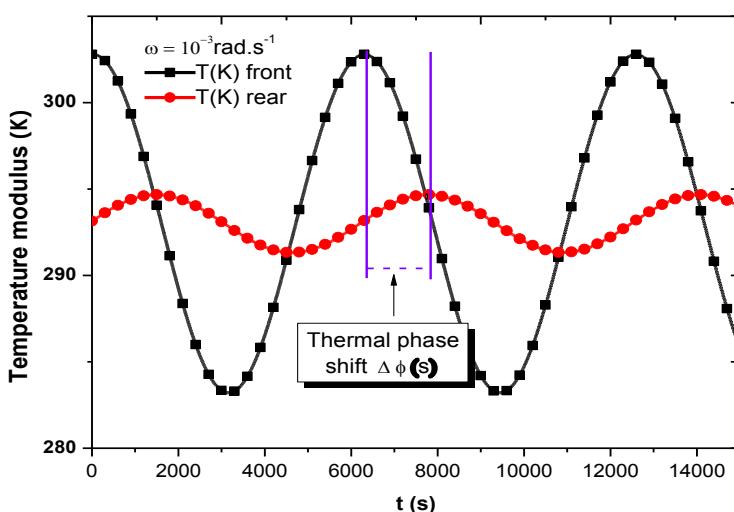
The resolution of this new equation and given the change of variable the expression of the temperature is given by (8):

$$T(x, h_1, h_2, \omega, t) = [A(h_1, h_2, \omega, t) \cdot \sinh(\beta x) + B(h_1, h_2, \omega, t) \cdot \cosh(\beta x)] \cdot \exp(i\omega t) + T_i \quad (8)$$

$A(h_1, h_2, \omega, t)$  and  $B(h_1, h_2, \omega, t)$  are coefficients given in the appendix.

#### METHOD OF GRAPHIC DETERMINATION OF THERMAL PHASE SHIFT

This method consists in plotting the temperature modulus of the front and rear faces as a function of time for a given excitation pulse. It should also be specified that the time is chosen so that  $t \succ T$  ( $T$  the period in seconds) so that the fluctuations of the temperatures of the two faces are visible.

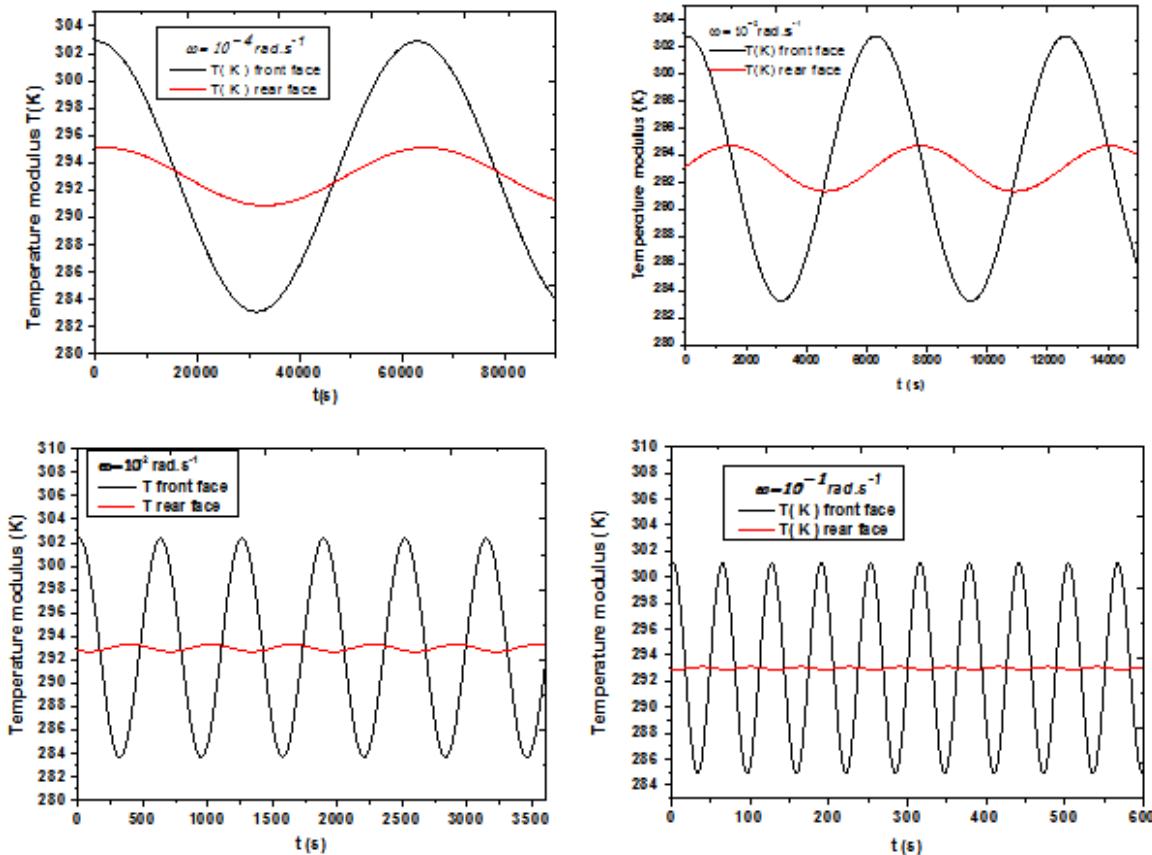


**Figure-2.** Temperature of the front and rear faces as a function of time.

The thermal phase shift  $\Delta\phi(s) = \phi_1 - \phi_2$  (with  $\phi_1$  and  $\phi_2$  the abscissa for the front and rear faces) is determined graphically by the time interval that elapses between the two maximums of the temperatures of the two faces.

#### RESULTS AND DISCUSSIONS

The following result is obtained for an excitation pulsation equal to  $10^{-3}$  rad.s<sup>-1</sup> with  $h_1=150$  W.m<sup>-1</sup>.K<sup>-1</sup> and  $h_2=5$  W.m<sup>-1</sup>.K<sup>-1</sup> so that the convective exchange at the rear face is weak. This makes it possible to visualize the influence of the perturbations of the front face on the latter.



**Figure-3.** Modulus the temperature of the front and rear faces as a function of time for different excitation pulses.

By observing Figure-3 above, we notice that the increase in the excitation pulsation leads to an increase in the frequency of the thermal stresses, hence the time difference between the maximum of the temperature at the front face and that of the rear face decreases. This shows that the thermal phase shift decreases with frequency.

However, the maximum amplitude of the temperature of the rear face is much more sensitive for the low frequencies. For  $\omega = 10^{-4} \text{ rad.s}^{-1}$  the temperature  $T_{\max}$

$= 295.1 \text{ K}$ ; i.e. an increase of 2.1 K compared to the initial temperature, whereas for  $\omega = 10^{-1} \text{ rad.s}^{-1}$  the temperature  $T_{\max} \text{ rear} = 293.1 \text{ K}$  is practically the same temperature as the initial temperature. This can be explained by the fact that for these frequencies the thermal wave is attenuated on small thicknesses [20]. The following table makes it possible to visualize this phenomenon.

**Table-1.** Correspondence between pulsation and thermal phase shift, temperature difference and period.

Pulsation $\omega(\text{rad.s}^{-1})$	Period $T(\text{s})$	Difference in temperature $\Delta T = T_{\max \text{ arrière}} - T_i (\text{K})$	Thermal phase shift $\Delta\phi (\text{s})$
$10^{-4}$	62832	2.1	1690
$10^{-3}$	6283	1.6	1438
$10^{-2}$	628	0.3	393
$10^{-1}$	63	0.1	37

Table-1 summarizes the corresponding period as well as the temperature difference and the thermal phase shift as a function of the excitation pulse. The thermal phase shift thus decreases when the excitation pulsation increases.

## CONCLUSIONS

In this work the heat transfer in one dimension is studied through a kapok plaster material in dynamic

frequency regime. From the temperature curve as a function of time, we have determined the thermal phase shift which decreases as the excitation frequency increases. However, the amplitude of the temperature at the rear face decreases with increasing frequency.



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