



Study of Energy Storage Phenomena in a Flat Wall Containing a Kapok-Plaster Material in Frequential Dynamic Regime- Influence of Depth

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ABSTRACT

We propose in this article, the study of the phenomena of energy storage in a wall in frequency dynamic mode. The optimal heat exchange coefficient and the maximum pulsation were determined from the temperature and flux density curves respectively. An electric-thermal analogy made it possible to determine the phenomena of energy storage from Bode diagrams of thermal capacity and thermal inductance.

Keywords: Storage energy, kapok plaster- frequential dynamic regime

Introduction

Faced with the ecological and environmental [1] problems that arise today, the issue of energy management is more topical than ever. Most countries are now targeting the reduction of greenhouse gas emissions in the long term. This drastic reduction in the building's energy needs can only be achieved through efforts on insulation, thermal inertia and energy saving.

We will explain a study of energy storage phenomena in the dynamic frequency regime [2]. Profiles of temperature and heat flux density curves highlight the phenomena of energy storage through the kapok-plaster [3] material proposed as thermal insulation under the influence of depth.

From the Bode diagrams of thermal capacity [4] and thermal inductance, we will indicate to show the phenomena of thermal inertia by adopting a thermal-electrical analogy.

Mathematical model

1. Diagram of the study device

The material is a flat wall whose thickness is of length L. It is subjected to external climatic stresses at the level of the two faces (front and rear). We consider that the heat transfer along the ox direction is perpendicular to the external stresses and the initial temperature of the material is non-zero.

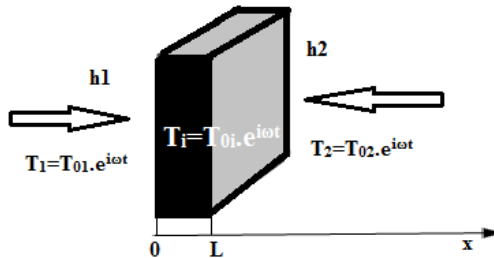


Fig. 1: Flat kapok-based wall plaster subjected to external stresses

2. Expression of temperature and heat flux density

The heat equation governing heat transfer in the wall (without a heat source or heat sink) is given by equation (1):

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\alpha} \cdot \frac{\partial T}{\partial t} = 0 \tag{1}$$

$$\text{with } \alpha = \frac{\lambda}{\rho \cdot C} \tag{2}$$

α thermal diffusivity.

λ thermal conductivity (W.m^{-1}), ρ density (kg.m^{-3})

Boundaries conditions

$$\lambda \frac{\partial T}{\partial x} = h_1 [T(0,t) - T_1] \quad (3)$$

$$\lambda \frac{\partial T}{\partial x} = h_2 [T_2 - T(L,t)] \quad (4)$$

Initial condition

$$T(x,t) = T_i \quad (5)$$

If we consider the variable $\bar{T} = T(x,t) - T_i$ then the equations (3), (4) et (5) become

$$\lambda \frac{\partial \bar{T}}{\partial x} = h_1 [\bar{T} + T_i - T_1] \quad (6)$$

$$\lambda \frac{\partial \bar{T}}{\partial x} = h_2 [T_2 - (\bar{T} + T_i)] \quad (7)$$

$$\bar{T}(x,0) = 0 \quad (8)$$

The solution to equation (1) taking into account the change of variable is:

$$\bar{T}(x, h_1, h_2, \alpha, t) = [A_1 \cdot \sinh(\beta(\omega, \alpha) \cdot x) + A_2 \cdot \cosh(\beta(\omega, \alpha) \cdot x)] \cdot e^{i\omega t} \quad (9)$$

$$T(x, h_1, h_2, \alpha, t) = \bar{T}(x, h_1, h_2, \alpha, t) + T_i \quad (10)$$

$$\beta(\omega, \alpha) = \sqrt{\frac{\omega}{2\alpha}}(1+i) \quad (11)$$

The expressions of the coefficients A1 and A2 are determined from the boundary conditions.[6,7]

$$A_1 = f(x, \omega, h_1, h_2, \alpha) \quad (12)$$

$$A_2 = f(x, \omega, h_1, h_2, \alpha) \quad (13)$$

Results and discussion

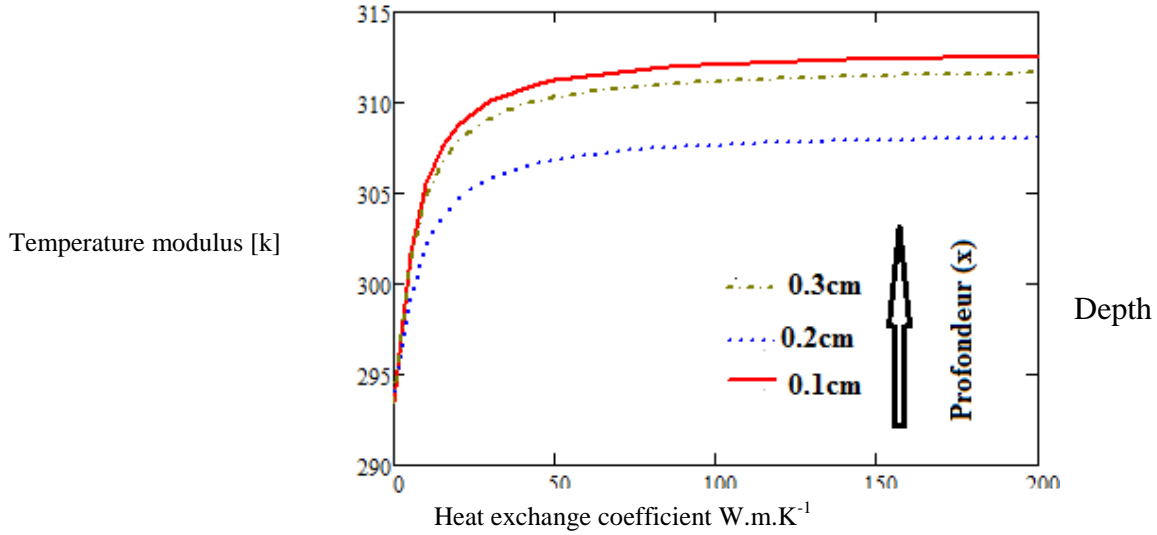


Fig 2 Evolution of the temperature according to the coefficient of exchange Influence of the depth; $h_2=5 \text{ W.m}^{-2}.\text{C}^{-1}$; $\omega = 2.10^{-3} \text{ rad/s}$

The temperature modulus is all the lower as the value of the exchange coefficient is low, this corresponds to weak heat exchanges between the external environment and the front face of the material. When the significant heat exchange coefficient [5] becomes high, the temperature modulus increases meaning that the heat exchanges are between the external environment and the wall of the material. This phenomenon is due to the strong absorption of heat. Thus the material has thus stored a maximum of energy and reached its thermal equilibrium. The optimum heat exchange coefficient is the heat exchange coefficient corresponding to thermal equilibrium. These values are represented in the following table:

Table 1: Influence of depth on the optimum heat exchange coefficient

Material depth x (cm)	Optimum heat exchange coefficient h_{op} ($\text{W.m}^{-2}.\text{C}^{-1}$)
x=0.1	$h_{op} = 100$
x=0.2	$h_{op} = 100$
x=0.3	$h_{op} = 100$

For different depth values, the optimal heat exchange coefficient is the same everywhere because thermal equilibrium is reached at these points.

2. Evolution of the flux density through the material

The heat flux density is given by the following relationship:

$$\phi(x, h1, h2, \alpha, t) = -\lambda \frac{\partial T}{\partial x} = -\lambda \cdot \beta \cdot (A_1 \cdot \cosh(\beta \cdot x) + A_2 \cdot \sinh(\beta \cdot x)) \quad (14)$$

The flux density modulus is all the more important as the depth is shallow. For low values of the pulsation, the flux increases and reaches a maximum and then decreases. When the pulse becomes weak, the modulus of the flux density increases said because the heat exchanges are important between the external environment and the material wall. The flux density modulus decreases as the pulsation increases. The decrease in flux density is due to the considerable absorption of heat by the kapok-plaster material. The latter stores more heat at shallow depths. The maximum exciter pulse [6] of heat transfer is the exciter pulse corresponding to the maximum modulus of heat flux density. These values are represented in the following table:

Table 2: Influence of depth on maximum pulsation.

Depth x (cm)	Maximum pulsation P _{ulmax} (rad/s)
x=0.1	2.81.10 ⁻⁷
x=0.2	1.2.10 ⁻⁷
x=0.3	6.59.10 ⁻⁸

The maximum excitatory pulsation decreases with increasing depth.

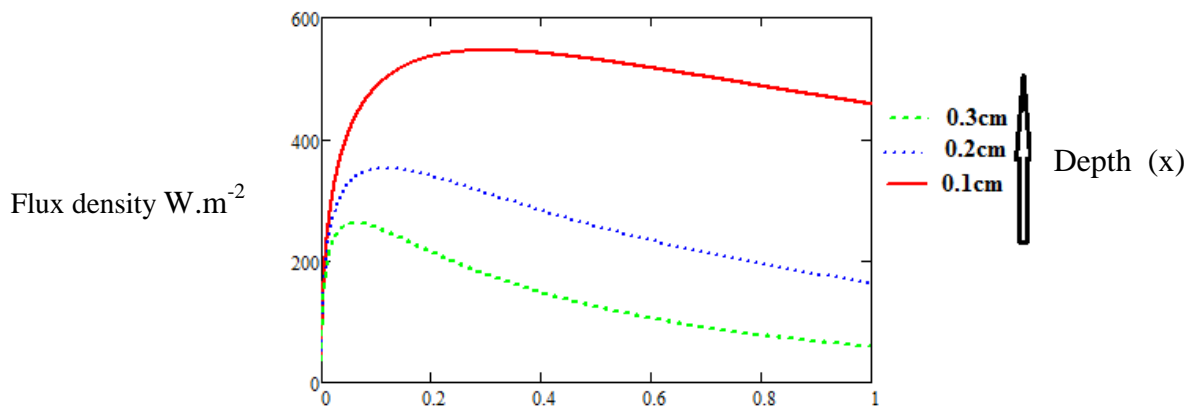


Figure 3: Evolution of the flux density according to the influence of the depth pulsation; h1=100 W.m⁻².C⁻¹, h2=5 W.m⁻².C⁻¹

IV Bode diagram of heat capacity and thermal inductance

1. Bode diagram of heat capacity

The expression for heat capacity is determined from the electric-thermal analogy:

$$I \longrightarrow \phi \quad \text{and} \quad \longrightarrow \Delta V \Delta T$$

$$C(x, \omega, h1, h2, t) = \frac{q}{\Delta V} = \frac{\int idt}{\Delta V} = \frac{\int_0^t \phi(x, \omega, h1, h2, t) dt}{\Delta T(x, \omega, h1, h2, t)}$$

This maximum value of the capacitance modulus translates the material storage phenomena. The higher the heat capacity, the greater the amount of heat the material can store. This, therefore, reflects the good quality of the thermal insulation that is the kapok-plaster. Because an insulator is all the more efficient when it can store large quantities of heat on very thin thicknesses [7]. This is what gives the material good thermal inertia.

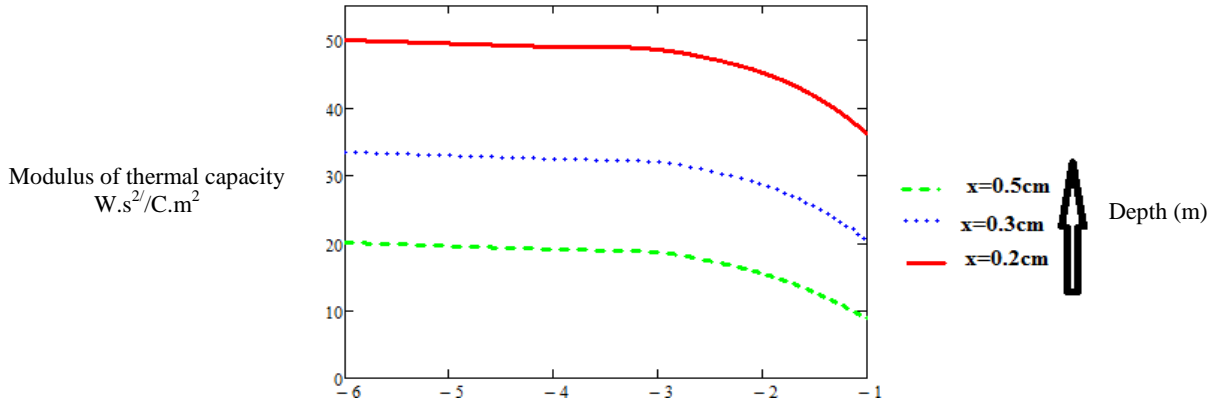


Figure 4 Heat capacity as a function of the decimal logarithm of the pulsation; the influence of depth.
 $h1=100 \text{ W.m}^{-2}.\text{C}^{-1}$, $h2=0.05 \text{ W.m}^{-2}.\text{C}^{-1}$

The expression of the thermal inductance is determined from the electrical-thermal analogy:

2. Bode diagram of thermal inductance

I ϕ \longrightarrow and $\Delta V \Delta T$ \longrightarrow

$$L(x, \omega, h1, h2, t) = \frac{\Delta T(x, \omega, h1, h2, t)}{\frac{d\phi(x, \omega, h1, h2, t)}{dt}}$$

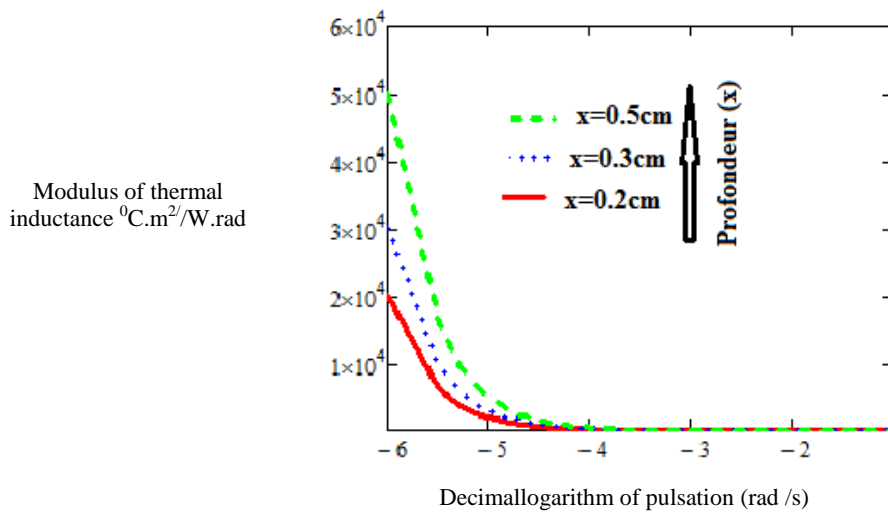


Fig 5 Heat capacity as a function of the decimal logarithm of the pulse; the influence of depth x

The thermal capacity modulus is maximum and constant for the values of the exciter frequency [8] lower than 10-3rad/s then decreases according to the exciter frequency. This maximum value of the capacitance modulus translates the material storage phenomena. The higher the heat capacity, the greater the amount of heat the material can store. This, therefore, reflects the good quality of the thermal insulation,[9] that is kapok-plaster. Because an insulator is all the more efficient when it can store large quantities of heat on very thin thicknesses. This is what gives the material [10] good thermal inertia.

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