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Research Article

Study of the Equivalent Electrical Capacity of a Thermal Insulating Kapok-plaster Material in Frequency Dynamic Regime Established

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Abstract: The study of heat transfer in frequency dynamic regime established helped define the thermal impedance of the material. The material is a plane wall composed of kapok-plaster with thickness of 0.01 m and a thermal conductivity 0.1 W/mK. The thermal behavior of the studied material is highlighted by showing the influences of heat transfer coefficients and external excitation pulse. L'evolution de la capacity equivalent intérêt Donnée en fonction de la pulsation excitatrice Extérieure. The evolution of the equivalent capacitance is given as a function of the external excitation pulse; the influences of the depth of the material, his diffusivity and heat exchange coefficients are shown.

Keywords: Equivalent capacitance, frequency dynamic regime, thermal impedance

INTRODUCTION

Energy saving in the home necessarily requires a good command of the thermal insulation of buildings (Dahli and Toubal, 2010; Meukam *et al*., 2004). Studies by different authors on the kapok (Voumbo *et al*., 2010a, b; Gaye *et al*., 2001), or combination of kapok and plaster have shown they are good thermal insulators biodegradable.

From of thermal electrical analogy (Dieng *et al*., 2013), we study the equivalent capacity of storage of heat.

METHODOLOGY

Study model: The material is a plane wall consisting of a mixture of plaster and kapok (Ould Brahim *et al*., 2011) whose thickness is of 10 cm. It is subjected to temperatures in frequency dynamic regime to the exterior and interior faces as shown in Fig. 1. h_1 et h_2 h and h are respectively the coefficients of heat exchange in the outer and inner surface. T_1 and T_2 are the temperatures in dynamic frequency regime of the outer and inner environments in direction (ox). T_{01} = 318 K (45°C) is the maximum temperature of the external environment and T_{02} = 273 K (0°C) is that the indoor environment. Heat exchange with the walls of the material is mainly through the convective heat transfer coefficient h_1.

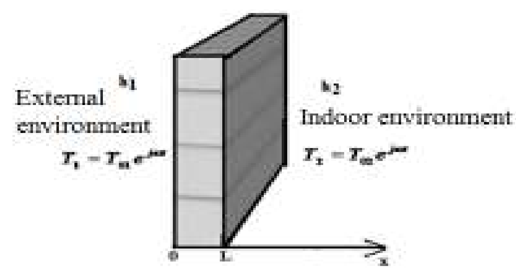

Fig. 1: Wall to kapok-plaster submitted the climatic solicitations

The heat transfer in one-dimensional in frequency dynamic regime is governed by the heat equation:

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

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

where,
α = The thermal diffusivity (m²/sec)

The boundary conditions:

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

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

The solution of the equation is (Ould Cheikh *et al*., 2013):

$$T(x,\omega,h1,h2,\alpha,t) = \begin{bmatrix} A_1 \cdot \sinh(r(\omega,\alpha)\cdot x) + \\ A_2 \cdot \cosh(r(\omega,\alpha)\cdot x) \end{bmatrix} e^{i\omega t} \quad (5)$$

où $r(\omega(\alpha) = \sqrt{\frac{\omega}{2\alpha}}(1 + i)$ (6)

The expressions of the coefficients A_1 and A_2 are determined from the boundary conditions:

$$A1 = f(x,\omega,h1,h2,\alpha) \quad (7)$$

$$A2 = f(x,\omega,h1,h2,\alpha) \quad (8)$$

The heat flux density is given by:

$$\phi(x,\omega,h_1,h_2,\alpha,t) = -\lambda \frac{\partial T(x,\omega,h_1,h_2,\alpha,t)}{\partial x} \quad (9)$$

The thermal impedance is defined by:

$$Z(x,\omega,h_1,h_2,\alpha,t) = \frac{\Delta T(x,\omega,h_1,h_2,\alpha,t)}{\phi(x,\omega,h_1,h_2,\alpha,t)} \quad (10)$$

L'analogie électrique thermique nous permet de déterminer la capacité thermique:

$$i \xrightarrow{correspond\ ing} \phi \text{ and } \Delta V \xrightarrow{corresponding} \Delta T$$

$$C = \frac{q}{\Delta V} = \frac{\int idt}{\Delta V} = \frac{\int_0^t \phi(x,\omega,h_1,h_2,\alpha,t)dt}{\Delta T(x,\omega,h_1,h_2,\alpha,t)} \quad (11)$$

By thermal-electrical analogy, we obtain an equivalent capacity $C(x,\omega,h_1,h_2,\alpha,t)$.

RESULTS

Study of the impedance by the bode diagram: The curves of Fig. 2a to c show the evolution of the

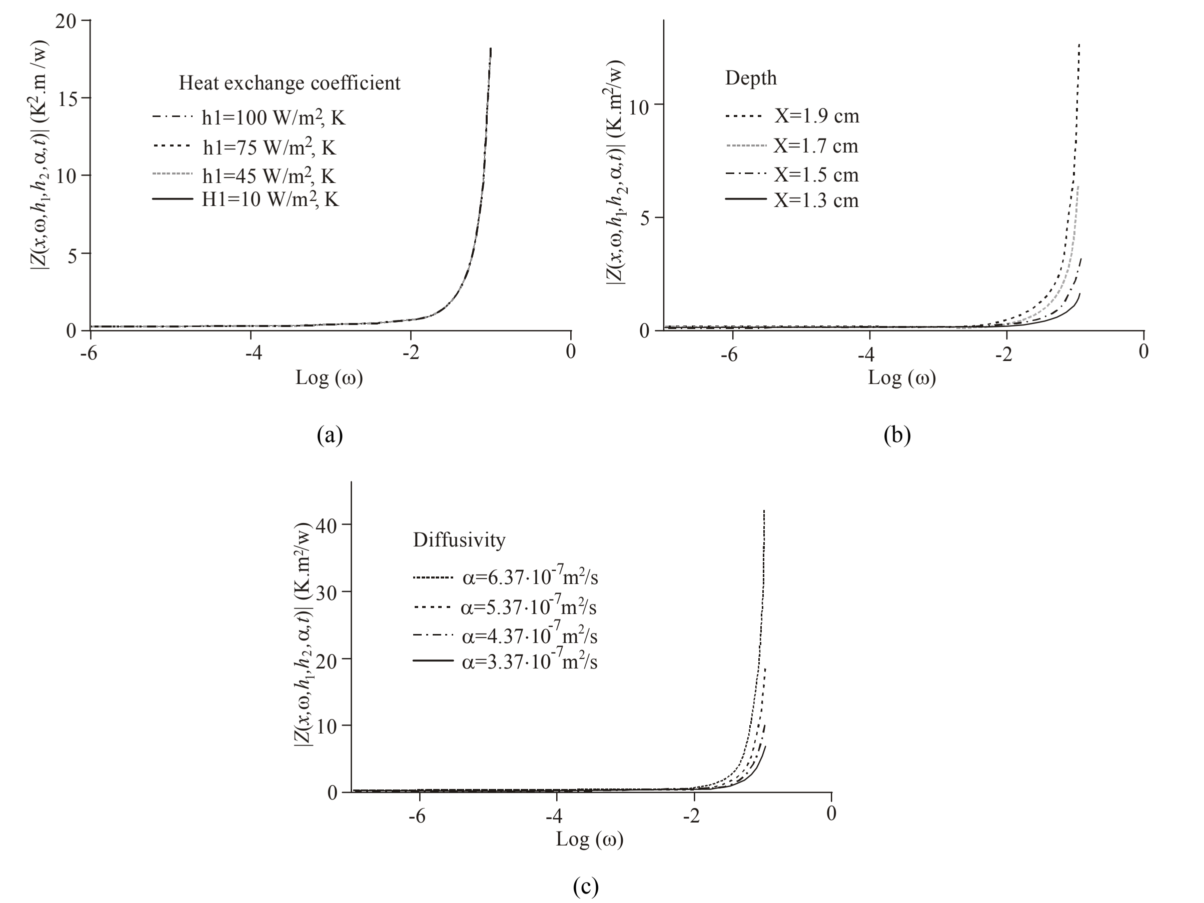


Fig. 2: Evolution of the module thermal impedance as a function of the excitation pulse; (a): $h_2 = 0.05$ W/m²/K, x = 2 cm, $\alpha = 4.37.10^{-7}$ m²/sec; (b): $h_1 = 20$ W/m²/K, $h_2 = 0.05$ W/m²/K, $\alpha = 4.37.10^{-7}$ m²/sec; (c): $h_1 = 20$ W/m²/K, $h_2 = 0.05$ W/m²/K, x = 2 cm

module of the equivalent impedance of the material $Z(x,\omega,h_1,h_2,\alpha,t)$, as a function of the logarithm of the outer exciter frequency. We respectively highlight the influences of heat transfer coefficient, the depth of the material and the diffusivity.

We regroup in Table 1 some module values of the thermal impedance.

The study of Fig. 2a to c evidence to suggest that the module thermal impedance is practically zero for low excitation pulses (low frequency); it is virtually a short circuit condition which results in a significant transfer of heat flux density.

For $\omega \approx 10^{-2}$ rad/sec, we have a dynamic situation with storage phenomena heat in the material.

For $\omega > 10^{-2}$ rad/sec and for the high frequencies, the impedance of the module becomes very large, which corresponds to an open circuit position; most of the heat is stored in the material. The kapok-plaster has a high thermal inertia.

The heat exchange coefficient influence slightly thermal impedance module contrary to the material thickness and the thermal diffusivity.

Study of the impedance by representations Nyquist: The curves of Fig. 3a to c show the variation of the imaginary part as a function of the real part of the thermal impedance of kapok-plaster material. The influences of the heat exchange coefficient, the depth and thermal diffusivity of material are highlighted.

Table 1: Some module values of the impedance corresponding to Fig. 2a to c

	h_1 (W/m^2/K)				x (10^{-2}.m)				α (10^{-7}.m^2/sec)			
	10	45	75	100	1.30	1.50	1.70	1.90	3.37	4.37	5.37	6.37
$\lvert Z(x, \omega, h_1, h_2, a, t)\rvert$ (K.m^2/W)	18.2	18.2	18.2	18.2	1.70	3.24	6.53	12.84	40.80	17.80	10.20	6.60

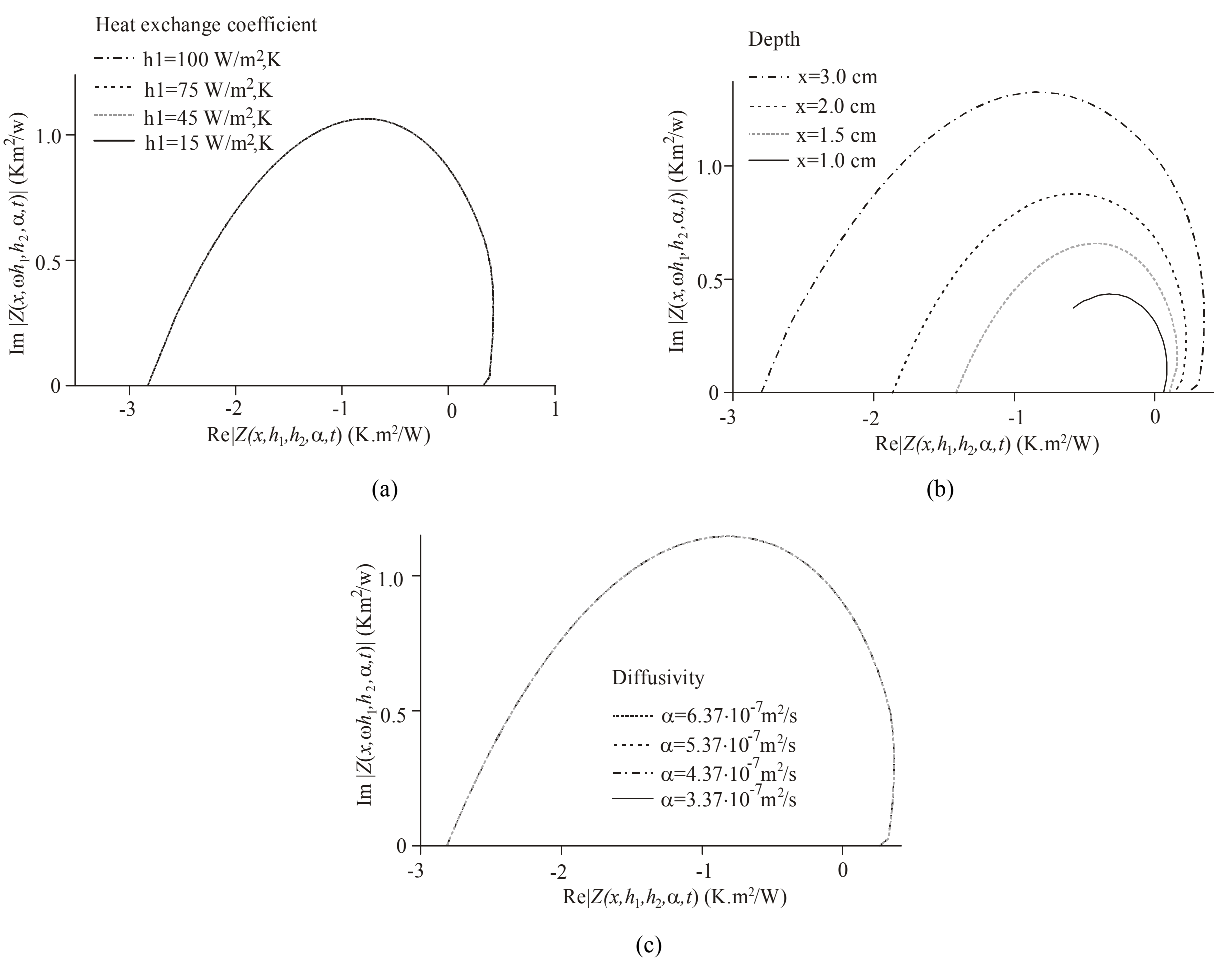


Fig. 3: Evolution of the imaginary part of the thermal impedance as a function of the real part; (a): h_2 = 0.05 W/m^2/K, x = 3 cm, α = 4.37.10^{-7} m^2/sec; (b): h_1 = 20 W/m^2/K, h_2 = 0.05 W/m^2/K, α = 4.37.10^{-7} m^2/sec; (c): h_1 = 20 W/m^2/K, h_2 = 0.05 W/m^2/K, x = 3 cm

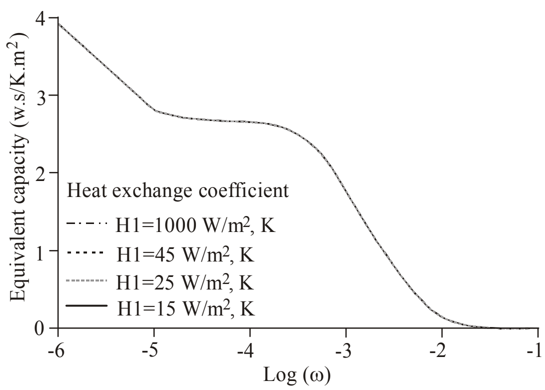
The Nyquist representations show firstly the existence of emmagasinement effect of energy by inductive or capacitive phenomena equivalent electrical (Fig. 3a to c). The heat retention depends primarily on the thickness of the material (Fig. 3b). The limit values for Im (Z) = 0 and Im (Z) is at maximum, to determine the series and shunt resistors, which are the phenomena of heat transfer to the high and low frequency. Table 2 gives some values of series resistors and shunt and thermal resistance $R_{th} = R_s + R_{sh}$. The thermal resistance translated from the phenomena of heat transfer to the absence of inductive and capacitive phenomena.

Equivalent capacitance of material: The study of the equivalent thermal impedance of the material confirmed the storage heat phenomena. The kapok-plaster thermal insulating is good if the high thermal inertia that is to say, its heat storage capacity is great. We translate this phenomenon storage heat by the equivalent capacitance of material. Figure 4a to c indicates the evolution of the equivalent capacitance in function of the excitation pulse. We observe a band of stability around $\omega \approx 10^{-4}$ rad/sec. In this band pulse, the material has a high thermal inertia.

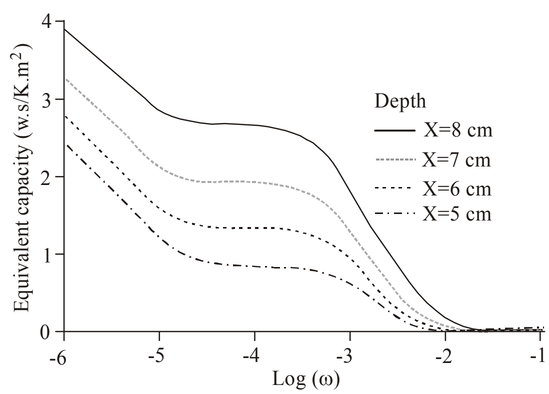
It should also be noted that the capacitive effects depend largely on the thickness of the material used and the thermal diffusivity. As against the heat exchange coefficient intervenes mainly on the thermal resistance that is to say, the heat transfer (Fig. 3a). Thermal resistance also depends also on the thermal conductivity (Jannot *et al*., 2009).

Table 2: Some values of series resistance (Rs), shunt (Rsh) or thermal (Rth) corresponding to Fig. 3a to c

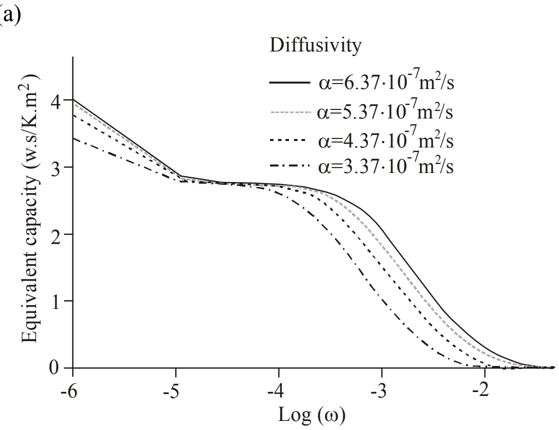
	h_1 (W/m²/K)				x (10^{-2} .m)				α (10^{-7} .m²/s)			
	15	25	35	1000	1.0	1.5	2.0	3.0	3.37	4.37	5.37	6.37
R_S (K.m²/W)	-1.97	-1.97	-1.97	-1.97	-0.59	-0.99	-1.38	-1.99	-1.98	-1.98	-1.98	-1.98
$R_{Th} = R_S + R_{Sh}$ (K.m²/W)	0.41	0.41	0.41	0.41	0.20	0.20	0.21	0.39	0.40	0.40	0.40	0.40
R_{Sh} (K.m²/W)	2.38	2.38	2.38	2.38	0.79	1.19	1.59	2.38	2.38	2.38	2.38	2.38



(a)



(b)



(c)

Fig. 4: Evolution of the equivalent capacitance in function of the excitation pulse; (a): $h_2 = 0.05$ W/m²/K, x = 5 cm, $\alpha = 4.37.10^{-7}$ m²/sec; (b): $h_1 = 20$ W/m²/K, $h_2 = 0.05$ W/m²/K, $\alpha = 4.37.10^{-7}$ m²/sec; (c): $h_1 = 20$ W/m²/K, $h_2 = 0.05$ W/m²/K, x = 5 cm

CONCLUSION

The quality of the thermal insulation is measured by its thermal inertia. The study by analogy electric-thermal has shown firstly the phenomena of heat storage with exploitations Bode diagrams and Nyquist representations. On the other hand, the model was used to study the evolution of the equivalent capacitance of kapok-plaster material. A frequency band appears stabilized, which corresponds to a material of good thermal inertia.

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